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AUTOMATIC DEPENDENT SURVEILLANCE BENEFIT AND COST ANALYSIS

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INTERIM REPORT

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16. Abstract

This study is a benefit and cost analysis of the economic and operational impacts of automatic dependent surveillance (ADS). The ADS function is currently under development and is designed to use satellite communications and advanced air traffic control (ATC) automation to improve air traffic services in oceanic and other airspaces. ADS will provide direct communication between pilots and air traffic controllers and enhanced ATC flight monitoring and airspace management capabilities. The study identifies the operational benefits and implementation requirements of ADS and analyzes their potential impacts on users and providers of air traffic services. Potential safety benefits are qualitatively assessed. Potential cost savings due to ADS operations are quantitatively estimated as are ADS system implementation costs. The expenditures considered in the analysis include user flight operating costs, air-ground communication user costs, aircraft ADS communication equipage costs, and ATC system enhancement costs. The study examines ADS implementation and potential operational impacts for the North Atlantic and Pacific oceanic areas. The resulting estimated cost savings due to ADS exceed the estimated implementation costs.

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PREFACE

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TO THE READER:

In an attempt to preserve the objectivity of the Automatic Dependent Surveillance (ADS) Benefit and Cost Analysis, some economic benefits were not included or were rated conservatively so as to preclude biasing the evaluation in favor of ADS. In a similar manner, cost estimates associated with implementing and maintaining ADS were skewed to the higher end of the cost range in cases of uncertainty. An example is the use of a restrained rather than an ambitious economy of scale factor in estimating the cost of equipment. Other cases of potentially high estimates include research and development and facility and equipment costs for ADS-based air traffic control system enhancements, ADS air-ground communication user charges, and retrofit installation costs for aircraft ADS equipment. Although this approach may have unduly penalized ADS, it does support the credibility of the evaluation results. The results showed ADS to be cost beneficial. Some of the factors which were considered from this conservative point of view are discussed in the following paragraphs.

The economic benefits of increased safety are difficult to quantitatively assess with accuracy. The prime attributes of ADS - timely reporting of aircraft position and improved message integrity - will provide the means for monitoring an aircraft's conformance with its assigned flight plan. This capability will significantly reduce the probability of an undetected deviation and provide timely blunder protection. The safety enhancement value of ADS increases when considering the current and projected traffic growth in the oceanic airspaces where ADS will be initially deployed. Although the safety enhancement impact of ADS was qualitatively analyzed in the study, no cost factor was assigned to this very real benefit.

Another significant consideration is the price of fuel. Fuel is the dominant component of flight operating cost, and flight cost saving is the basis for the economic benefit attributed to ADS in this study. Estimates of flight cost saving were based on recent and prevailing fuel prices, which have been volatile. The study performed a sensitivity analysis to evaluate the effects of changes in the fuel prices estimated for future years. This analysis concluded that net savings due to ADS would be realized over a meaningful range of fuel price.

The allocation of costs to aircraft communications equipage for ADS was a conservative 50 percent. Although ADS for air traffic services is the prime motivation for ADS, expected use of the equipment for airline operational communications, airline administration communications and airline passenger communication could far exceed the aggregate allocation assumed for those functions.

This interim study was restricted in scope by the resources available, and could not examine in extensive detail all issues relevant to ADS benefit and cost analysis. Such issues should be addressed in further analysis efforts. For example, the consequences of partial ADS fleet equipage and the continuation of a high frequency communication service are jointly related and complex. There are other significant factors for which data has not been fully developed which will affect the relative cost of ADS and the resultant benefit. The extent to which high frequency service should properly be considered as part of ADS service costs should be addressed. The deployment of newer satellites with spot beams, the overall implications of non-air traffic services communications, the budgetary plans of various air traffic control providers, and the cost amortization procedures employed by various data sources need attention. An expanded assessment of these factors may find that the ADS costs may be much less than those estimated in the study. The cost impacts pertaining to these and other considerations require careful investigation based on data beyond those currently assembled.

This benefit and cost analysis used data available from United States air traffic control authorities and United States-based air carriers and communication services. The study base needs to be broadened to include an international perspective. Hence, an invitation is extended to the international aviation community to provide additional quantitative data describing operations and cost factors as deemed appropriate.

In summary, although the additional analysis required to provide a more accurate benefit and cost study is recommended, the conservative approach taken in this initial analysis ensures the validity of results and clearly shows the benefit of implementing ADS.

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EXECUTIVE SUMMARY

This benefit and cost study analyzes the potential impacts of proposed automatic dependent surveillance (ADS) implementations in the North Atlantic and Pacific oceanic airspaces. ADS, which is currently under development, is designed to use satellite communications and advanced air traffic control (ATC) automation to improve air traffic services. This capability would be particularly effective in airspaces where radar coverage is not available and where high-frequency (HF) technology provides indirect air-ground voice communication between pilots and air traffic controllers. Operationally, ADS would use digital data link to provide frequent updates of aircraft position reports and direct air-ground communication between pilots and controllers. These capabilities would improve oceanic air traffic controllers' ability to monitor and manage air traffic.

BENEFITS

ADS would be the basis for potentially significant enhancements in flight safety and would support potentially significant reductions in flight operating costs.

Safety Enhancements -- Current HF-supported oceanic air traffic operations are vulnerable to certain flight navigation errors associated with human blunders by pilots, controllers or radio operators. Examples include waypoint insertion errors and ATC communication loop errors. The ADS-based ATC automation would be capable of detecting the occurrence of many such errors, and ADS-based direct pilot-controller communication would expedite their resolution and prevent potential mishaps.

Flight Operating Cost Savings -- In association with improved aircraft navigation performance, ADS would support reductions in separation minima. Separation minima reductions would alleviate delays and diversions from preferred flight paths, and would significantly reduce flight operating costs in comparison with current oceanic operations. ADS also would support improved ATC flexibility, which would enable controllers to be more responsive to air traffic flight preferences with or without separation minima reductions and would contribute to flight operating cost savings.

COSTS

The realization of ADS benefits will require expenditures to implement, maintain and use the ADS system. ADS would require: expenditures by users of the satellite-based air-ground communication system for data link message transmission services; expenditures by aircraft operators for ADS communication equipage; and expenditures by ATC provider authorities for ADS system development and facility and equipment enhancement programs.

ADS Air-Ground Communication User Costs -- The implementation and maintenance costs incurred by providers of satellite-based air-ground communication service would be recovered through user charges. The user costs pertaining to ADS are those associated with ATC and other air traffic services message transmissions. The ADS messages include aircraft position reports, pilot clearance and information requests, controller clearance instructions, meteorological reports, weather advisories and emergency communications.

Aircraft Satellite Communication Equipment Costs -- Aircraft operators would incur expenses for satellite communication equipment purchases, installations of the equipment on aircraft, and continual maintenance of the equipment.

ATC Provider Costs -- ATC provider authorities would incur expenses to establish and support ADS-based air traffic services. These expenses account for research and development of ATC hardware, software and procedural enhancement, ATC facility preparation and equipment procurement, and continual operating and maintenance requirements.

BENEFIT AND COST COMPARISON

Since the ADS establishment, operating and maintenance costs could be considerable, the value of developing ADS depends on the relative balance between implementation costs and the benefits achievable. This study qualitatively assesses the potential safety benefits of ADS and quantitatively assesses ADS system costs and flight cost savings. Costs and savings are evaluated for the North Atlantic and Pacific for the years 1990 through 2010. The areas under study include airspace jurisdictions of Canada, Iceland, Japan, Portugal, the United Kingdom, and the United States (US).

The study compares ADS operations and costs with those of a baseline system. The baseline system represents ATC operations with the Oceanic Display and Planning System (ODAPS) or equivalent ATC automation. ODAPS is being developed and implemented by the US, and comparable systems are being or will be developed by other ATC provider authorities.

Flight cost savings due to reduced separation minima are estimated by updating the results of previous computerized simulations of baseline and ADS operations. The updates account for traffic loading and aircraft type distribution changes based on recent surveys and forecasts and for current and projected aircraft flight performance characteristics. Flight cost savings due to improved ATC flexibility are based on analyses of potential reductions in flight diversions. The cost saving estimates are adjusted to account for ADS coverage limitations based on proposed configurations of the satellite constellation and ADS-based ATC service limitations based on reported ADS implementation plans of ATC provider authorities.

Estimates of aircraft satellite communication equipment costs are based on analyses of the relevant cost factors. These factors include the unit price of the equipment, the number of aircraft in the ADS fleet, the number of aircraft requiring retrofit installation versus the number of aircraft that are fully-equipped new deliveries, and operating and maintenance requirements.

Estimates of ADS air-ground communication user costs and ATC provider cost are based on data provided for US programs and operations. These estimates, subject to revision, are used to also represent non-US costs.

The US ADS program plan includes a transition period for the step-wise introduction and establishment of ADS. This benefit and cost study assumes that full ADS operations with reduced separation minima would commence at the start of 1995. To facilitate the initial cost analysis, 100% of the participating oceanic aircraft is assumed to be ADS equipped starting in 1995. The study develops estimates of ADS-based flight cost savings for the years 1995 through 2010. However, all relevant implementation costs during 1990 through 2010 are included. Costs and savings are estimated in 1990 US dollars and inflated at a 5% compound annual growth rate for subsequent years. To enable economic comparisons, the 1990 present values are calculated using compound annual discount factors of 10% for ATC provider authority costs and 12% for the other costs and the flight cost savings.

The 1990 present value of the potential net savings is estimated to be $176.6 based on the results of this interim study:

	1990 Present Value ($ million)	
Flight Cost Saving due to:		
Reduced Separation Minima	$502.7	
Improved ATC Flexibility	$41.7	
Total Saving		$544.4
ADS Air-Ground Communication User Cost Increase	$41.3	
ADS Equipage Cost for Aircraft Operators	$213.2	
ADS System Cost for ATC Providers	$113.3	
Total Cost		$367.8
NET SAVING		$176.6

These results represent the discounted values of the costs and savings estimated for the years 1990 through 2010.

COST FACTORS

The key assumptions used to develop the cost and savings estimates are described in the following paragraphs. Cost estimates are in 1990 US dollars.

Flight Operating Cost Factors -- A fuel price of $1.00 per gallon is assumed based on costs reported for 1990. A sensitivity analysis indicates that significant net benefits would still result under reasonable variations in the fuel price or the fuel price inflation rate.

ADS Air-Ground Communication User Cost Factors -- ADS satellite communication user costs are assumed to be incurred at a rate of $1.20 per kilobit processed. A typical ATC data link message is assumed to require one-half kilobit, including message management overhead, which results in an estimate

of $.60 per ADS message. ADS position reports are assumed to be transmitted at 5 minute intervals from each aircraft, and other data link messages are assumed to increase ADS message loading by an additional 10%. The cost recovery requirement of the baseline HF voice communication system is assumed to total $20 million annually for the North Atlantic and Pacific airspaces under study.

Aircraft Satellite Communication Equipment Cost Factors -- The purchase cost of satellite communication equipment for one aircraft is assumed to be $137,000, which accounts for a satellite communication unit, data management unit, ADS unit and low gain antenna. Retrofit installation cost is assumed to be $100,000 per aircraft. Annual maintenance cost is assumed to be 6% of the installed cost. The low gain antenna would support ADS communication as well as airline operational communication and airline administrative communication. ADS is assumed to account for 50% of these data link messages, and the equipment cost is allocated accordingly. Although high gain antennae may be installed to provide air-ground digital voice communication, the high gain antennae are not assumed to be an ADS requirement and their cost is not considered in the study. The study assumes that 1200 aircraft are ADS-equipped by 1995, 1400 by the year 2000 and 1840 by the year 2010. New deliveries are assumed to account for 300 ADS-equipped aircraft by 1995, 500 by the year 2000, and 940 by the year 2010. Retrofit installations of ADS equipment would apply to 900 aircraft.

ATC Provider Cost Factors -- The ATC system research and development cost relating to ADS is assumed to be $7 million each for the six provider authorities. Facility and equipment cost is assumed to be $7 million each for the nine ATC centers responsible for air traffic services in the airspaces under study. Annual maintenance cost is assumed to be 2.5% of the facility and equipment cost, which allows for replacement of baseline ODAPS equipment.

AUTOMATIC DEPENDENT SURVEILLANCE
BENEFIT AND COST ANALYSIS

1. INTRODUCTION

The automatic dependent surveillance (ADS) function is designed to use satellite communications and advanced air traffic control (ATC) automation to improve air traffic services in oceanic and other airspaces. ADS is currently under development by the international aviation community. When implemented, it will provide direct communication between pilots and air traffic controllers and enhanced ATC flight monitoring and airspace management capabilities. ADS would be the basis for potentially significant improvements in flight safety, and, in association with improved aircraft navigation performance, would support potentially significant reductions in flight operating costs.

The implementation of ADS and the realization of benefits will require expenditures for research and development, ATC and aircraft equipment acquisition and maintenance, and communication system use. Since these costs could be considerable, the value of developing ADS depends on the balance between implementation costs and the benefits achievable. This study is undertaken to evaluate and examine the relative costs and benefits.

The study identifies the operational benefits and implementation requirements of ADS and analyzes their potential impacts on users and providers of air traffic services. Potential safety benefits are qualitatively assessed. Potential cost savings due to ADS operations are quantitatively estimated and compared with ADS system implementation cost estimates.

1.1 Analysis Scope

The study focuses on the ADS program of the United States (US). The US program is directed to the implementation of ADS in North Atlantic and Pacific oceanic airspaces. Hence, this study examines ADS impacts on air traffic systems and operations in the North Atlantic and Pacific. Since air traffic services to flights through these international oceanic airspaces are provided by the US and numerous other states, an assessment of ADS should consider impacts on the international oceanic air traffic system. This study uses data available from US sources to conduct the analysis and develop cost estimates. To enable the study to address impacts beyond the US program, the estimates derived from US data are extended to represent international impacts.

The US has developed the Oceanic Display and Planning System (ODAPS), an ATC automation feature. ODAPS is a planned predecessor to ADS and is currently under operational implementation. This study considers oceanic ATC operations with ODAPS as the baseline system. ADS represents an incremental improvement to ODAPS-based baseline operations.

1.2 Method of Approach

This study is based on ADS descriptions (references 1, 2, 3, 4, and 5), previous operations analyses and benefit and cost evaluations (6, 7, 8), and operational observations and consultations with aviation industry and related specialists. A major contribution is the Oceanic Area System Improvement Study (OASIS). OASIS (7) examined present and potential future oceanic air traffic services, communication and navigation systems, modeled and evaluated future operational impacts, and developed and applied procedures to quantify and compare system costs. It assessed capital investment, operations, and maintenance costs for system providers and users. OASIS conducted a detailed analysis of flight operating costs for alternative oceanic aircraft separation minima, which provides a useful basis for addressing ADS impacts.

The present benefit and cost study analyzes current and projected plans and operations, in part by updating and extending the OASIS assessments. The tasks performed are:

- Describe System Alternatives -- Review and identify communication, navigation, and surveillance technology, operating procedures, aircraft separation minima, user flight preferences and related information pertaining to current and proposed ADS operations.

- Describe Oceanic Operations -- Review and identify traffic operating and congestion characteristics in the North Atlantic and Pacific airspaces.

- Describe Potential Safety Benefits -- Identify current operating circumstances vulnerable to flight errors which are subject to prevention or correction with ADS.

- Update Flight Data and Traffic Forecasts -- Assemble, analyze and incorporate data describing traffic loading, fleet composition by aircraft types, traffic forecasts, and aircraft flight performance characteristics.

- Estimate Flight Cost Impacts -- Update the OASIS analysis of ADS-based flight cost savings to represent current traffic and aircraft fleet composition forecasts and estimate savings due to improved ATC flexibility.

- Estimate Other System Costs -- Evaluate projected communication system user costs, aircraft equipment costs, ATC system enhancement costs, and related expenses pertaining to the continuation of the current system and ADS implementation.

- Assess Benefits and Costs -- Compare flight cost savings and other cost impacts estimated for ADS and non-ADS operations and investigate the sensitivity of cost impacts to parametric variations.

The US program (3) includes a transition period for the step-wise introduction and establishment of ADS. This benefit and cost study assumes that full ADS operations may commence at the start of 1995, and develops estimates of ADS-based cost savings for the years 1995 through 2010. However, all relevant

costs during 1990 through 2010 are included. Costs are estimated in 1990 dollars and inflated at appropriate rates for subsequent years. Comparisons are made using present values of costs and savings discounted to 1990.

This interim study is limited to the use of readily accessible data and descriptive information. Resources do not allow the systematic solicitation of additional data from the international aviation community, the initiation of special surveys, or the development and application of complex modeling and analysis procedures. First-cut approximations are made where necessary to estimate cost impacts where specific data are not obtained. The cost estimates, analyses and results are described in the remainder of this report.

2. BASELINE OCEANIC SYSTEM OVERVIEW

Air traffic service is provided within designated areas of international airspace by contracting states under the auspices of the International Civil Aviation Authority. Air traffic service includes ATC, flight information and alerting functions. The method for providing air traffic service in an area is largely dependent on the communication, navigation and ATC automation systems in use. The capabilities of these systems determine the operational procedures, practices, route structures, requirements and rules, including separation minima, that may be employed.

2.1 Baseline Technology

In most oceanic areas, communication and navigation technologies are required to operate over long distances, involving over-the-horizon applications. Line-of-sight systems typically employed in domestic operations do not satisfy this requirement. Hence, very high-frequency range (VHF) and ultra high-frequency (UHF) equipment are precluded. These include VHF/UHF air-ground communication systems; VHF primary and secondary surveillance radar (SSR) systems; and VHF omnidirectional range (VOR), distance measuring equipment (DME), military UHF tactical air navigation (TACAN) and combined VOR and TACAN (VORTAC) radionavigation systems. Low-frequency nondirectional beacon (NDB) radionavigation facilities used by aircraft equipped with automatic direction finder (ADF) units provide a longer service range than VHF/UHF radionavigation facilities, but do not provide intercontinental coverage.

Aeronautical Mobile Communications -- Long-range air-ground communication between pilots and controller is conducted indirectly using high-frequency (HF) voice facilities. Radio operators in communication stations on the ground speak directly with pilots using HF and relay messages between pilots and oceanic air traffic controllers. In the United States (US), teletype is normally used by radio operators to relay pilot-generated messages to controllers, while direct speech circuits are used to send voice messages from controllers to radio operators for subsequent relay to pilots.

HF transmissions are subject to interference by atmospheric disturbances that degrade voice quality. These signal propagation problems have been countered in part by the use of multiple frequencies and single sideband (SSB) HF modulation. Selective calling (SELCAL) systems enable a radio operator to send a tone signal to a specific aircraft prior to voice message transmission, thus alleviating pilots of the need to continuously listen to sometimes noisy HF channels.

Aeronautical Fixed Communications -- In addition to the communication stations' operations, point-to-point voice and data communications are conducted among air traffic service units, including centers, towers and flight service stations, commercial aircraft and military base operations offices, meteorological services and other facilities. The fixed communications system includes air traffic service direct speech networks, the aeronautical fixed telecommunication network (AFTN), and various meteorological and data transmission networks. The networks consist of landlines, satellite links, marine cables, HF and VHF point-to-point channels,

and switching sites for routing messages among facilities. The links may be dedicated to voice or data transmission or shared by each, and may be leased from commercial or public communications services.

Navigation -- Long-range navigation is commonly accomplished by using Inertial Navigation System (INS) avionics or the "Omega" radionavigation system. Both operate on a worldwide, continuous basis. The widespread use of INS and Omega has allowed the phasing out of the older Long Range Navigation (LORAN) A facilities. However, LORAN C, Doppler and celestial navigation may be used. LORAN C coverage is provided in the continental US and offshore areas. Newly-developing satellite-based navigation systems could become available for worldwide civil aviation use. These include (4) the global/standard positioning service (GPS/SPS), GLONASS, and GEOSTAR systems.

Aircraft flying through the upper airspace region of part of the North Atlantic oceanic airspace are required to satisfy a stipulated navigation precision standard known as the Minimum Navigation Performance Specification (MNPS). INS, Omega and the satellite-based navigation systems satisfy the specification and are applicable throughout the MNPS airspace.

ATC Automation -- The US Federal Aviation Administration (FAA) is installing ODAPS in the New York and the Oakland Air Route Traffic Control Centers. ODAPS sector equipment include a plan view display console, a flight data input/output device, and a flight strip bay. ODAPS automates various data management and traffic assessment activities that otherwise would be manually performed by oceanic controllers. ODAPS, when fully operational, provides various capabilities (4) including:

- o Oceanic flight data processing
- o ODAPS-based traffic situation display
- o Flight plan conflict probe
- o Trial plan conflict probe
- o ODAPS-based message and list displays, including:
  - Flight data
  - Predicted conflicts
  - Overdue reports
- o Automated flight strip generation
- o Automated interface with North American Air Defence Command

Comparable automation systems are being implemented or are under development at other oceanic ATC centers serving the North Atlantic and Pacific areas.

2.2 Baseline Operations

Flight plans filed by aircraft operators are distributed to oceanic ATC centers through aeronautical fixed communications facilities. The requested route and flight level data in the flight plan are used by controllers to determine oceanic clearances for aircraft prior to their entry into oceanic airspace. Oceanic entry clearances are normally negotiated and issued through domestic air-ground communications facilities. A clearance assignment is based on comparisons of the aircraft's requested route and flight level with the current and projected positions of other aircraft with respect to established separation minima. If the requested assignment would cause a violation of

separation minima, an alternative assignment is developed to resolve the potential conflict. The alternative may involve aircraft delay, lateral diversion from the requested route, vertical diversion from the requested flight level, or combinations of delay and diversion. Controllers often provide pilots with delay and diversion alternatives for selection.

Once in oceanic airspace and beyond the coverage of domestic navigation and air-ground communication facilities, long-range navigation techniques and position reporting procedures are implemented. Pilots transmit flight progress reports indirectly to controllers using the HF voice communications facilities. These reports enable controllers to perform flight-following operations. A progress report includes the aircraft identification, the current reporting position identification, altitude and crossing time, the next reporting position identification and estimated crossing time, and the next subsequent reporting position identification. Progress reports are transmitted for mandatory reporting positions as well as for additional fixes if requested by controllers. Reporting fixes usually are located at the intersection of a flight track and ten degree longitude lines or five degree latitude lines depending on east-west or north-south flight direction. Reports are issued at 45 to 75 minute intervals depending on a flight's geodetic location and direction. Other messages transmitted by pilots include clearance change requests which are made to achieve more fuel efficient flight paths or to avoid turbulence. For example, a step climb may be requested when an aircraft burns enough fuel to lower its weight so that it may fly at the higher flight level.

US controllers manually copy pilot report and request data on to paper flight progress strips. The pilot report also is automatically processed by ODAPS. ODAPS updates the traffic situation display by extrapolating progress report data and factoring-in meteorological and flight plan clearance data. The fully operational ODAPS (4) would perform separation minima violation checks at current and projected downstream positions, and could be used to probe trial flight plans for potential conflicts in response to pilot clearance change requests.

In the event of a potential conflict, the controller determines the appropriate resolution action. The resolution, which may be a clearance revision, a fix crossing time or altitude restriction, or a pilot request denial, is transmitted to the pilot indirectly using the HF voice communication facilities. Pilot acknowledgment would also be relayed through the HF radio operator.

Communication among oceanic ATC centers is performed to coordinate control strategies and tactics, such as potential conflict resolution actions and pilot request responses, and to forward flight data, such as boundary crossing time estimates. These interfacility voice or digital data messages would be carried by the aeronautical fixed communication system circuits.

3. ADS OVERVIEW

Operationally, ADS will improve controllers' ability to monitor and manage air traffic in a non-radar environment. ADS technology includes communication and automation facilities and associated software. ADS uses satellite data link channels and supporting ground stations and terrestrial distribution networks to transmit messages directly between pilots and controllers. Under the ADS concept as currently planned, flight progress information derived from an aircraft's navigation system will be automatically transmitted by data link. ADS automation in ATC facilities will process the flight progress data and perform error detection, situation display and tabular display updating, potential conflict resolution assessment, and other operations. Controller work stations with electronic flight data displays and advanced man machine interface features will replace the ODAPS flight data input/output equipment. Pilots and controllers will compose and send data link messages using the automation interfaces and uplink and downlink communication components. A downlink-only phase is planned (3) for introductory operations, followed by the implementation of the uplink capability. Descriptions of ADS are given in references 1 through 5.

ADS reports are planned to have three formats: the basic ADS report, the extended ADS report, and the associated ADS report. The basic ADS report will include current position, altitude and time data and a figure of merit describing position data accuracy for the on-board navigation system. It will be automatically transmitted from the aircraft at 5 minute intervals. Additional reports could be sent at variable rates upon controller request, up to a maximum rate of once every 10 seconds. The extended ADS report will include the position and crossing altitude for the next two waypoints, track or heading, speed, and climb or descent rate data. The associated ADS message will include wind and temperature data. The extended and associated ADS reports will be transmitted from the aircraft upon controller request. (1-5)

Apart from ADS, the satellite data link operation will provide direct air-ground communication with non-ATC facilities, including airline operations offices. The HF voice system would be displaced as the primary oceanic aeronautical mobile communications service. The satellite service also would support (4) air-ground digital voice communications if appropriate aircraft, satellite and ground station equipment are provided.

3.1 Safety Impacts

A major impact of ADS will be its ability to significantly enhance flight safety. These enhancements are based on improvements relating to the baseline system's potential for human error and limitations in HF pilot-controller communications.

Baseline Safety Considerations -- The current baseline operation is vulnerable to a class of flight navigation errors caused by human blunders. These arise when a pilot, controller, or HF radio operator makes an operational mistake which is not detected and corrected in a timely manner. A classic example is the waypoint insertion error in which a pilot enters incorrect planned position data into the INS units and causes the aircraft to fly off of its cleared course. Also, inadvertent track deviations by the pilot could occur for an aircraft under manual flight control. These deviations would not be recognized by a controller, even with ODAPS, unless a progress report is received that differs from the clearance. An aircraft could fly off its course for nearly an hour before a pilot transmits an HF voice report. Even then, the incorrect coordinates might not be recognized and transmitted by the pilot.

ATC loop errors typically involve an information processing mistake by a human. For example, a controller may issue an instruction, such as a flight level assignment, that is different from the intended clearance. The controller may simply misread the altitude in the voice message to the radio operator although the correct assignment might be entered in the computer data base and on a flight strip. Similarly, a radio operator might incorrectly relay an instruction to a pilot, and a pilot might incorrectly hear or transcribe an instruction. Pilot acknowledgement messages may lead to the immediate detection by a controller of many of these errors, but even the acknowledgement review process is subject to human cognitive lapses. A person may scan a teletype or computer displayed message but not comprehend that it contains erroneous information, even when manually copying the data. Such oversights might occur, for example, with the handling of routine, repetitive messages during busy traffic situations when mental, perceptual and motor capabilities are stressed or during very light workload periods when attentiveness may be of concern.

The HF voice communication operation has a lag time between the issuance of a message by a controller or a pilot and receipt of a response from the other party through the radio operator relay. A lag time of the order of 5 to 10 minutes may be typical (7), and could be longer. The lag time could be critical for situations involving in-flight emergencies as well as those requiring controller corrective intervention or advisory issuance. These situations include hijacking, engine outage, loss of cabin pressure, out-of-conformance with clearance or separation requirements, hazardous weather conditions and others where the controller's ability to quickly respond to pilot needs is important. The communications lag may be alleviated by patching a special HF voice connection between a controller and a pilot when warranted, but such a patch requires time for set-up.

The lengthy interval of near an hour between HF progress reports limits the effectiveness of the air traffic services alerting function. The timing of a controller's recognition of an overdue report depends on the reporting interval. The longer the interval, the later the overdue report recognition. Furthermore, search and rescue missions need accurate information describing the location of aircraft in distress. Subject to the effectiveness of emergency locator transmitters in large oceanic areas, these missions would rely on the most recent progress report to help locate a missing aircraft. The older the report, the larger the surface area required for searching, and the more difficult the search.

ADS Safety Enhancements -- Advanced ATC automation functions are designed to use the ADS reports to resolve many flight safety concerns. The conformance monitoring function will automatically analyze each basic ADS position report to assess an aircraft's out of tolerance status with respect to its clearance. The ADS-reported position will be compared with the estimated position derived from the flight plan clearance. Because of the frequency of the ADS reports, this function will be able to conduct a timely detection of a pending or existing clearance deviation caused by human error. In the case of a lateral or vertical out of tolerance situation, the automation will report the detected deviation to the controller for immediate corrective intervention. Two-way direct pilot-controller data link communications will facilitate the intervention. This capability will help prevent inadvertent violations of separation minima and incursions into restricted airspace.

Longitudinal deviations from estimated position will also be checked by the automation. Detection of an along course deviation will generate updates to the calculated time of arrivals at downstream fixes and flight plan conflict probes of aircraft separations. If a separation violation is predicted, it will be automatically reported to the controller for resolution.

Data contained in extended ADS reports will be automatically analyzed to predict potential clearance deviations. The waypoint validation function will perform a search for waypoint insertion errors. It will compare an aircraft's reported coordinates for its next fixes to the flight plan clearance and will report discrepancies to the controller for corrective intervention. The automation will also search for erroneous flight level entries.

The satellite data link system will provide nearly instantaneous pilot-controller communications, which will eliminate the lag time of the HF voice communication system and allow rapid message exchanges during time-critical situations.

Frequent ADS reporting and automation functions which check the reasonableness of reported positions and warn of overdue reports will provide reliable aircraft location data and timely updates and advisories. These would enable early recognition of potentially missing aircraft, early issuance of alerts, and delivery of recent , accurate position data to search and rescue personnel.

The ADS safety enhancements will utilize navigation information transmitted from the aircraft, and therefore could not detect or predict deviations due to performance anomalies intrinsic to an aircraft's navigation system. For example, an intrinsic drift off course by an INS that is correctly set to the cleared flight plan would not be detected. Similarly, incorrect pre-flight initialization of INS position data may not be recognized by ADS-based automation. However, the potential safety impacts of ADS are important in view of the variety of errors that can be corrected given the continual possibility of their occurrence. Numerous instances of oceanic clearance deviations have occurred, many of which may have been preventable by ADS.

3.2 Flight Operation Impacts

The route and flight level requested by an aircraft are based on a detailed analysis of route structure characteristics, meteorological forecasts, airplane flight performance characteristics, aircraft estimated weight and reserve fuel requirements, and operating procedures. The flight plan analysis normally emphasizes the selection of the minimum cost flight path although flight time and passenger comfort may also be considered. The resulting preferred flight path is typically the one that achieves the minimum fuel burn. A delay or a diversion from the economically preferred route or flight profile would increase flight operating cost.

ADS in association with reduced separation minima and more flexible oceanic ATC procedures will provide opportunities to alleviate delays and diversions and thereby lessen flight operating costs. These potential improvements are described in the following paragraphs, and their potential impacts on flight costs in the North Atlantic and Pacific areas are quantitatively analyzed in Sections 4 and 5 of this report.

Separation Minima Reduction -- The separation minima currently established for oceanic operations are based in part on historic aircraft navigation performance characteristics and in part on the ability of controllers to monitor air traffic flight progress and intervene to correct clearance deviations and resolve potential conflicts. Controller intervention capabilities are highly dependent on the communications, surveillance and automation systems in use. In the baseline oceanic environment, where direct pilot-controller communication and independent surveillance do not exist, the separation minima are mainly determined by navigation performance characteristics. The resulting horizontal separation minima are large. For example, separation minima in the MNPS airspace under typical operating procedures are 60 nautical miles (nmi) laterally and 10 minutes (min) longitudinally. For comparison, the basic domestic radar separation minimum is 5 nmi in en route airspace. The 2000 feet (ft) vertical oceanic separation minimum above flight level 290 conforms with domestic operations where the same avionics equipment is used to maintain altitude. The rules (9) vary within and among oceanic areas according to procedures and support facilities.

Observations (10) made during recent years indicate that the performance characteristics of state-of-the-art long range navigation systems have improved significantly over those upon which the current separation minima were originally established. Further, ADS-based communication and automation will significantly improve controller monitoring and intervention capabilities, particularly in regard to abilities to detect and correct many large navigation errors. The navigation system performance improvement along with the ATC operational advantages associated with ADS-based communication and automation provide a basis for proposed (1) reductions in horizontal separation minima to 30 nmi laterally and 5 min longitudinally.

The resulting potential reductions in delays and diversions will be particularly significant in areas of congested oceanic air traffic, and are important in other areas as well. Aircraft serving common origin and destination markets compete for airspace. Requests from two aircraft for the same route and flight level at approximately the same time are not uncommon, and require controller resolution. Speed differences between successive

aircraft on the same route and flight level also need to be accounted for to prevent violations of longitudinal separation minimum due to flight overtakes. Clearly, reducing the longitudinal separation minimum will increase the number of aircraft that could be cleared onto a given route and flight level per unit time. The expected waiting time for entry on to any route and flight level will be decreased, and the likelihood that an aircraft may be assigned its preferred or a nearby alternative route or flight level is increased. Similarly, reducing the lateral separation will increase the number of routes available per unit of airspace. Route spacing will be decreased, and the likelihood that an aircraft may be assigned its preferred flight level within a reasonable distance of its preferred route will be increased. Furthermore, reductions in these horizontal separation minima will reduce the likelihood that aircraft on crossing routes would potentially conflict with each other. The overall effect of reduced lateral and longitudinal separation minima will be a reduction in the frequency and magnitude of delays and of lateral and vertical diversions from preferred flight paths.

Improved Oceanic ATC Flexibility -- The ODAPS traffic situation display assists controllers in following and visualizing flight progress and the ODAPS flight plan conflict probe and trial amendment probe assist controllers in maintaining proper separations and determining clearances. ADS, with its more frequent position report updates, more advanced automation, and two-way direct pilot-controller communications, will be a basis for further enhancing ATC operations. In comparison to the ODAPS baseline system, ADS will provide more information describing aircraft movement, increase the level of confidence controllers have regarding traffic information, and improve the capability of controllers to assess alternatives, issue clearances and conduct timely situation interventions when needed. These factors will provide opportunities to develop and apply a broader range of control techniques, where circumstances permit, for the purpose of increasing ATC responsiveness to aircraft needs. Such techniques would be applicable with or without changes to separation minima.

Informal consultations with US oceanic controllers who compose the ADS Systems Requirements Team discussed impacts of ADS on controller operations. The discussions identified some ADS-tailored techniques that may be useful, particularly in areas where procedures are not constrained by highly-structured route systems. These suggested techniques were offered as examples of potential implementations for consideration. Any actual procedural change associated with ADS operations would involve an extensive development, review and approval process.

The System Requirements Team controllers addressed techniques for resolving potential conflicts between two aircraft. For example, consider the situation in which two aircraft are flying towards each other at different flight levels on a reciprocal courses. The lower aircraft may request a step climb to a flight level above the oncoming flight. It may be cleared to do so either after the aircraft pass each other or before, subject to separation requirements. Current longitudinal separation procedures (9) require the aircraft to be vertically separated for a time interval equal to the applicable minimum required before and after the aircraft are estimated to pass, unless both aircraft have reported passing a significant point and satisfy the longitudinal separation minimum. When using time estimates, the time interval during which vertical separation applies is twice the separation

minimum. ADS reporting will provide position data more frequently and quickly than does HF voice reporting. The ADS situation display will show the reporting points as they are updated in near real time, assisting the controller in confirming aircraft positions. These ADS capabilities will facilitate the issuance of a climb clearance based on the receipt of reports confirming the establishment of proper separation, which may enable the lower aircraft to climb to a preferred flight level sooner than under HF operations. The time interval during which vertical separation is typically applied to aircraft on reciprocal courses may be reduced by one-half.

ADS-based techniques which take advantage of the controller's more frequent confirmations of positions and better knowledge of separation may be applicable to the general case of potentially conflicting aircraft on crossing or reciprocal courses in which lateral and longitudinal separation requirements are taken into consideration. These techniques may enable the issuance of clearances that expedite discontinuance of vertical separation, such as described in the preceding paragraph, resulting in a reduction in the time spent by aircraft at non-optimum flight levels. Also, conflict probes and frequent situation display updates of extrapolated aircraft positions would further assist the controller in comprehending changing circumstances and responding to them.

Off-course climb and descent is a controller-suggested ADS technique to separate an aircraft from higher traffic on nearby routes in response to a flight level change request. Using frequent ADS reports to confirm its position and help monitor its movement, the controller may clear the subject aircraft off its track and away from the other aircraft until proper horizontal separation is established. The aircraft may then be cleared to climb or descend past the proximate traffic and, subsequently, return to its requested route. The off-coarse climb technique conceivably may be applied to resolve a case in which one aircraft is cleared to cruise under another for an extended time but prefers to climb above the other aircraft.

More timely responses to pilot requests will be facilitated with ADS because of the elimination of the lag time inherent in HF voice communications. This improved responsiveness will reduce the time required to request and grant preferred flight paths. It will expedite track and altitude changes.

Secondary interactions involving requests for changes also will be impacted by timely responsiveness and improved situation monitoring. For example, step climbs may be constrained by same-direction traffic on the higher flight levels of a route. The lower aircraft may be required to wait for an opening created by an altitude change by a higher aircraft or by increased inter-aircraft spacing due to speed differences on the higher flight level. In the first situation, the lower aircraft's approval might not be issued until the higher aircraft is confirmed to be established at a new upper flight level. Without ADS, confirmation could require an HF voice message from the pilot reporting from the new flight level. With ADS, the automatic altitude reporting and situation display capabilities would preclude delays due to HF communications lag and pilot discretion in the timing of the HF message initiation. Similarly, increased inter-aircraft spacing would be recognized earlier with ADS reports rather than HF progress reports. These improvements will be effective on routes with significant traffic, especially densely-populated, highly-structured route systems.

3.3 ADS Air-Ground Communication User Impacts

Progress reports are the most frequently occurring type of pilot-controller communication in the baseline operation. Other types of messages include clearance instructions, clearance confirmations, clearance change requests, requests for pilot reports, weather advisories and emergency communications.

The predominance of progress report type messages will increase in ADS operations with the use of basic, extended and associated ADS reports. Additional types of messages introduced with ADS will include clearance deviation notifications, discrepancy between air-derived flight plan data and clearance notifications, and variable rate report requests. Because the basic ADS reports will be transmitted at least every 5 minutes rather than nearly hourly, the number of messages transmitted with ADS will be significantly more than in the baseline operation. However, an ADS data link message will be significantly shorter than a comparable HF voice message.

Air-ground communications services may be provided under contractual arrangements. The providers of the services incur expenses for the fixed facilities, leasing, labor and related functions required for airspace segment message transmission and ground segment message processing and network distribution. The providers recover their capital and operating and maintenance costs through user charges. The users charges for HF voice communications in the US portion of the baseline system reportedly (11) are determined each year based on the providers' accrued annualized costs. Satellite-based ADS data link communications are expected to be charged directly according to message loading.

The cost of providing the satellite-based communication service will differ from that of HF voice communications. The cost difference to the users is quantitatively analyzed for the North Atlantic and Pacific areas in Section 6 of this report.

3.4 ADS Aircraft Equipage Impacts

ADS air-ground message transmissions require satellite communication equipment on board aircraft. Aircraft operators would assume the responsibility for purchasing, installing and maintaining the equipment. The aircraft satellite communication equipment costs pertinent to ADS operations are quantitatively analyzed in Section 7 of this report.

3.5 ATC Provider Impacts

ATC provider authorities will incur expenses to establish and support ADS-based air traffic services. These ATC system enhancement expenditures will account for the research and development of advanced automation and procedures, ATC facility preparation and equipment procurement, and associated operating and maintenance requirements.

The ADS-based ATC enhancement to the baseline ODAPS operation will introduce additional automation features designed to expedite controller operations, including:

- o Conflict resolution function
- o Conflict probe function on out-of-conformance situation
- o Deferred requests recall function
- o ADS work station with:
  - Message and list displays
  - Message creation/generation functions
  - Message display format control and prioritization functions
  - Message recall function
  - Common denominator function
  - Group broadcast function
  - Message analysis and display functions (e.g., emergency code recognition)
- o Data recording, archiving and playback

These features will facilitate data link communications tasks, which will supplant time consuming voice forwarding and manual data copying work, and situation recognition and assessment tasks. The ADS automation features will enable controllers to perform tasks more efficiently and effectively than with baseline ODAPS equipment, hence alleviating workload. However, controllers may be expected to be more attentive to the ADS situation display than in the baseline operation and more active in the application of techniques associated with ATC operational flexibility. This increased work would counterbalance some of the workload alleviation aspects of ADS automation. Overall controller workload is not expected to increase with ADS implementation and may decrease in comparison to baseline ODAPS operations. The changes in workload due to ADS are not expected to be sufficient to substantially affect sector manning requirements and annual staffing levels.

The elimination of ODAPS flight data input/output equipment will remove devices which contribute to maintenance workload. But the ADS workstations, which will be more complex than the ODAPS equipment being replaced, and the associated ADS functionality may increase maintenance and data systems support requirements somewhat.

The remaining baseline ATC facility staff, including administrative, management, training, data processing and other positions, may be able to absorb ADS-related responsibilities without a significant change in the number of personnel.

For the purposes of this study, the general assumption is made that non-maintenance ATC facility staffing and related operating requirements, relative to baseline ODAPS levels, would not be significantly increased by the implementation of full ADS operations. ADS would require ATC system enhancement expenditures for research and development, facilities and equipment, and operations and maintenance. These ADS-related ATC provider costs are estimated in Section 8 of this report.

4. NORTH ATLANTIC OCEANIC AREA

North Atlantic traffic operations and potential ADS impacts are described in this section. The operational descriptions address oceanic traffic loading and forecasts, fleet composition, and congestion characteristics. Flight operating costs are quantitatively analyzed.

To facilitate the quantitative analysis, ADS equipment is assumed to be installed on-board all the aircraft operating in the North Atlantic airspace (i.e., 100% ADS fleet equipage). The analysis initially assumes complete ADS coverage in the oceanic airspace, and radar or ADS-equivalent service in adjacent airspaces. These analytical assumptions provide the basis for estimating the cost savings theoretically possible with ADS implementation. The estimated cost savings are then adjusted to account for limitations associated with ADS implementation plans and anticipated ADS coverage.

4.1 North Atlantic Operations

The North Atlantic air traffic is composed mostly of commercial subsonic jet aircraft, but also includes military, commercial supersonic transport (SST), and general aviation aircraft. Table 1 shows the flight distribution by traffic flow group and operator class for a July, 1988, average sample day. The Table 1 statistics are obtained from the most recent report (12) of the North Atlantic Traffic Forecasting Group (NAT TFG) available at the time of this analysis and are based on surveys of actual traffic. The traffic flow designations shown in Table 1 are those defined by the NAT TFG to describe geographic origin and destination groupings for non-stop flights. These flows are:

1. Scandinavia - to/from - North America, all (SCAN - NAM)
2. Europe, excluding the Iberian Peninsula and Scandinavia, and the Middle East - to/from - North America/East (EUR - NAM/EAST)
3. Europe, excluding the Iberian Peninsula and Scandinavia, and the Middle East - to/from - North America/Midwest (EUR - NAM/MIDWEST)
4. Europe, excluding the Iberian Peninsula and Scandinavia, and the Middle East - to/from - North America/West, excluding Alaska (EUR - NAM/WEST)
5. Europe, including Scandinavia, excluding the Iberian Peninsula, and the Middle East- to/from - Caribbean, South and Central America, and Bermuda (EUR,SCAN - CAR,SA)
6. Iberian Peninsula and the Azores - to/from - United States of America and Bermuda (IBE - USA)
7. Iberian Peninsula and the Azores - to/from - Canada (IBE - CAN)
8. Iberian Peninsula and the Azores - to/from - Caribbean, South and Central America, and Bermuda (IBE - CAR,SA)
9. North Africa - to/from - North America, all, and the Caribbean and Bermuda (N.AFR - NAM,CAR)
10. Europe, all - to/from - North America/Alaska only (EUR - NAM/AK)
11. North America, all - to/from - Caribbean (NAM - CAR)

Table 1. North Atlantic Daily Flight Distribution

Flow	Subsonic Commercial	Mil-itary	Super-Sonic Transport	General Aviation	Total
	Number of 1988 Daily Flights by Aircraft Operator Group				
1. SCAN-NAM	54	4	0	6	64
2. EUR-NAM/EAST	477	27	8	16	528
3. EUR-NAM/MIDWEST	73	0	0	C	74
4. EUR-NAM/WEST	50	1	0	0	50
5. EUR,SCAN-CAR	70	0	0	0	71
6. IBE-USA	28	10	0	1	39
7. IBE-CAN	10	0	0	1	11
8. IBE-CAR	13	0	0	0	13
9. N.AFR-NAM	8	1	0	0	9
10.EUR-NAM/AK	19	0	0	0	19
11.NAM-CAR	145	4	0	4	153
All	948	47	8	28	1032
Percent	92%	5%	1%	3%	

Table 1 lists the total daily number of flights in both directions (e.g., eastbound plus westbound) for each flow. Commercial subsonic aircraft are predominant on each flow and account for 92% of the daily total. Aircraft in this category are turbojets, have comparable flight performance characteristics, and generally prefer to cruise in a common flight level (FL) range between FL310 and FL410 (i.e., pressure altitudes 31,000 and 41,000 ft above sea level). Hence, commercial subsonic aircraft have a propensity to compete with each other for preferred airspace and account for almost all of the delay and diversion experienced in oceanic airspace. Certain military and high performance general aviation aircraft also mix in with the commercial subsonic flights. Slower military transport aircraft in particular contribute to overall congestion because of the increased longitudinal spacings required to prevent overtake conflicts.

The SST aircraft cruise well above the other aircraft, and do not interfere with subsonic air traffic. The Other General Aviation category shown in Table 1 contains piston aircraft which fly below the turbojet aircraft, and do not interfere with the commercial subsonic turbojet flights. The volume of SST and piston general aviation aircraft traffic is not sufficient to generate significant congestion within each of these categories.

Routes flown by aircraft include published and random routes or tracks. A published route or track may be fixed and defined on aeronautical charts or it may be temporary. A random route or track is initially defined by the aircraft operator during the flight planning process and applies to an individual flight.

Northern North Atlantic -- Of the total 1032 daily flights, 58% are concentrated in a major traffic flow between Europe (excluding Scandinavia and the Iberian Peninsula) and North America (east and midwest). This major traffic flow, because of passenger preference, time-zone differences, and restrictions on nighttime jet airport operations, consists of two distinct traffic surges: one westbound leaving Europe in the morning and early afternoon and the other eastbound leaving North America in the evening. The preferred routes generally run between Newfoundland and the British Isles, causing a concentration of air traffic in this oceanic corridor. As a result, an Organized Track System (OTS) is established twice daily to serve the two surges. The OTS is designed to conform with the upper air circulation pattern and general route preferences projected for the current day and time period. It consists of a set of roughly parallel tracks with eastbound and westbound flight level assignments. The track placements and flight level assignments are made such that the lateral and vertical separation minima are satisfied at all points along each track.

Aircraft using the OTS may compete with each other for preferred airspace. The competition occurs even though different origin and destination pairs tend to spread the track preferences of individual flights, different aircraft types and weights tend to spread their flight level preferences, and different analysis procedures and meteorological data sources tend to spread both their track and flight level preferences. These factors tend to disperse the traffic on the OTS, but are not sufficient to prevent a significant number of potential conflicts. These potential conflicts occur because the volume of traffic on the OTS is sufficient to maintain an aggregate coincidence of primary and secondary flight preferences among a meaningful proportion of the flights. The resulting "packing" of air traffic leads to delays and diversions at oceanic entry as well as in oceanic airspace when requesting clearance changes.

The major traffic flow is roughly paralleled by two lesser traffic flows: one to the north between Scandinavia and North America, and the other to the south between the Iberian Peninsula and North America. These flights may use random routes outside the OTS airspace. However, depending on meteorological conditions and origin and destination locations, flights in these lesser flows may often prefer routes that potentially conflict with major flow flights on OTS tracks. For example, flights between the Iberian Peninsula and Canada may prefer to join, cross, or depart OTS tracks. Difficulties in merging with OTS traffic are alleviated somewhat when tributary tracks are designated which join the Iberian Peninsula with a southerly OTS track at midocean. Such designations may require flight level assignment compromises between the major flow and tributary tracks. Additional full OTS tracks may be established and dedicated to the Iberian traffic. Scandinavian flights may elect to fly entirely on an OTS track or on a random route rather than risk diversion from a preferred midocean OTS merge. A series of fixed routes connecting northern Europe to Iceland to Greenland to northern Canada exists and is used by short range aircraft.

Flights between Europe and western North America, including Alaska, utilize random routes in oceanic airspace. Flights to and from the western conterminous US and western Canada fly over northern Cañada, Greenland, and the Iceland vicinity. These may compete for airspace with the Scandinavian and major flow traffic depending on meteorological conditions. Polar flights to and from Alaska fly over the Arctic Ocean.

In all cases, flights are subject to potential airspace competition with other flights within their respective traffic flows.

Western North Atlantic -- Table 1 shows a secondary major flow between North America and the Caribbean, accounting for 15% of the total daily flights. This traffic is generally north-south in orientation, with individual route preferences often crossing each other because of the location of the origin and destination airports. Most of the flights are between airports in the northeastern US and eastern Canada and airports spread among various Caribbean islands. This distribution pattern results in a high concentration of flights in the geographically confined airspace between the North American east coast and Bermuda. These flights normally are of considerably shorter range than most other North Atlantic flights. To accommodate these flights, a relatively complex network of crossing oceanic routes are established in the western North Atlantic joining points on the east coast of North America, Bermuda and Caribbean islands. These routes are based on NDB/ADF navigation techniques, are published as fixed tracks, and are maintained by routine flight-checks of the radionavigation aids. Flights on these routes are subject to significant delay and diversion because the magnitude of traffic is sufficient to generate potential airspace competition among a meaningful proportion of the traffic.

Central North Atlantic Flights in the remaining North Atlantic airspace are mostly between Europe, including Scandinavia and the Iberian Peninsula, and the Caribbean and the US. These fly on random routes or on two published fixed routes running from the Iberian Peninsula towards the Caribbean, terminating in mid-ocean. A network of fixed routes also connects the Iberian Peninsula and the Azores.

These trans-Atlantic flights compete for airspace with each other and can interfere with other traffic. For example, congestion occurs south of the mid-ocean terminals of the two fixed routes running towards the Caribbean. Here, circumstances often arise where traffic between northern Europe and the eastern Caribbean (e.g., United Kingdom and Barbados) and traffic between southern Europe and the northern Caribbean (e.g., Spain and Puerto Rico) cross in mid-ocean before or after flying on each of the two fixed routes. Analogous situations occur east of Bermuda where random route traffic exists. Traffic between Europe and various locations in the US and the Caribbean cross each other at points spread over a large expanse of airspace, generating potential conflicts.

Flight planning may alleviate congestion but not eliminate flight cost penalties, as in the case of Caribbean-bound flights from the British Isles and northern Europe. These flights may prefer to cross the eastern part of the major traffic flow. Instead, based on previous experience, such flights may request sub-optimal flight levels below the OTS to expedite their trip and avoid further delays and diversions.

The remainder of this study focuses on commercial subsonic turbojet traffic because of their dominant influence on system operations and costs.

4.2 North Atlantic Flight Operating Cost Savings

The flight cost impacts of reduced separation minima and improved oceanic ATC flexibility are described separately in the following paragraphs.

North Atlantic Separation Minima Reduction Cost Impact -- OASIS was part of a worldwide oceanic aeronautical system improvement study program coordinated by the informal Committee to Review the Application of Satellite and Other Techniques to Civil Aviation. The Committee, which included the participation of over 20 states and international aviation organizations, provided inputs and guidance to OASIS and served as a forum for reviewing analysis procedures and results. OASIS developed and applied the computerized Flight Cost Model, which simulated aircraft operations and costs in various ATC environments. It replicated traffic loading patterns, route structures, meteorological conditions, fuel consumption and other flight performance characteristics by aircraft type, airline flight planning procedures, separation minima and variations as applied in different airspace segments and operating situations, and the control procedures and delay and diversion strategies used by controllers. The Flight Cost Model was used to estimate user fuel, crew, and maintenance costs for alternative separation minima and operations corresponding to the existing oceanic system and selected potential improvements, including ADS.

The Committee conducted a vigorous critical review of the Flight Cost Model to confirm its accuracy in representing real-world flight operations and costs. Existing operating procedures and realistic alternatives for future operations were taken into account. Because this validation exercise was conducted by expert authorities from the international aviation community, the Flight Cost Model is considered an effective and legitimate tool for evaluating flight cost savings due separation minima reductions.

The Flight Cost Model is complex, requiring extensive resources for its operation. These requirements are beyond the scope of this ADS study. However, the Flight Cost Model modeling logic is representative of current baseline and proposed ADS operations. Hence, the Flight Cost Model results previously obtained by OASIS are valid provided updates are made to account for those conditions that have changed since OASIS was completed. The pertinent changes concern traffic loading and forecasts, aircraft fleet composition, aircraft fuel consumption characteristics and fuel price. The OASIS Flight Cost Model results were adjusted to account for these factors, and the key updates are summarized in Tables 2, 3, and 4.

Commercial subsonic turbojet traffic data by flow for a July sample day and a November sample day are presented in Table 2. Table 2 is based on NAT TFG data (12) and shows daily traffic statistics for the survey year and corresponding daily traffic forecasts for the years 1994 and 2010. The July day has more traffic than the November day on each flow except the North America-Caribbean and the Europe-Alaska flow. The July day reflects the busy summer travel season on the trans-Atlantic flows.

Table 2. North Atlantic Subsonic Commercial Daily Traffic Data

	Number of Daily Flights					
	July Sample Day			November Sample Day		
O-D Flow	1988	1994	2010	1988	1994	2010
1. SCAN-NAM	54	63	86	48	39	53
2. EUR-NAM/EAST	477	446	611	265	391	536
3. EUR-NAM/MIDWEST	73	76	104	28	55	75
4. EUR-NAM/WEST	50	60	82	24	37	51
5. EUR,SCAN-CAR	70	51	70	32	43	59
6. IBE-USA	28	30	41	12	26	36
7. IBE-CAN	10	14	19	4	6	8
8. IBE-CAR	13	15	21	9	11	15
9. N.AFR-NAM	8	10	14	3	6	8
10.EUR-NAM/AK	19	22	30	40	24	33
11.NAM-CAR	146	196	269	147	202	277
All	948	983	1347	612	840	1151

Distributions of flights by aircraft type category for each flow are shown in Table 3. The aircraft type category definitions are those developed by the NAT TFG (12), as are the survey year data and the 1994 forecast. The forecast for 2010 is based on OASIS data (13). The projections assume a phasing out of the older narrowbody aircraft, such as the B707, DC8, IL62, and B727, and an increase in newer-generation twin-engine aircraft, such as the B767, B757, A300 and derivatives. However, the three and four engine wide-bodies are forecast to maintain their dominance. These aircraft are mostly B747's, but include others such as the DC10, L1011 and derivatives. The forecasts assume an evolutionary increase in the percentage of larger versions of the B747, such as the B747-400.

The fleet mix forecast was analyzed in detail to develop quantitative descriptors of fuel consumption and crew and maintenance cost characteristics by flow. Current flight performance data for representative aircraft were obtained from airlines and manufacturers. The performance data include fuel mileage (i.e., nmi per 1000 pounds of fuel) by flight level, aircraft weight, and cruise speed. Current cost rates (i.e., $ per hour) for crew and direct maintenance of airframes, engines and other flight equipment by representative aircraft were obtained from industry reports (14), as were fuel prices (15). These statistics were compared with corresponding data (16) developed from OASIS, and used to update the OASIS Flight Cost Model analysis of North Atlantic flight operating costs. Extrapolations were made to extend the OASIS data to the year 2010 and to conform with current NAT TFG flow definitions. Specifically, the Arctic Ocean polar flights were not part of the OASIS analysis, and cost savings for the Alaskan traffic were estimated by comparisons with analogous flows. The results for the survey year, 1994 and 2010 are given in Table 4 in 1990 dollars, without inflation or discount adjustments.

Table 3. North Atlantic Traffic Distributions by Aircraft Type

Flow	High Altitude Wide Body (B747SP)	Other Wide Body	Three & Four Engine Narrow Body	Twin Engine Wide & Narrow Body
		1988 Traffic		
1. SCAN-NAM	0%	57%	35%	7%
2. EUR-NAM/EAST	0%	80%	12%	7%
3. EUR-NAM/MIDWEST	0%	73%	7%	21%
4. EUR-NAM/WEST	0%	92%	8%	0%
5. EUR,SCAN-CAR	0%	81%	19%	0%
6. IBE-USA	0%	75%	18%	7%
7. IBE-CAN	0%	50%	50%	0%
8. IBE-CAR	0%	77%	23%	0%
9. N.AFR-NAM	0%	75%	25%	0%
10. EUR-NAM/AK	0%	100%	0%	0%
11. NAM-CAR	0%	38%	41%	21%
All	0%	72%	18%	10%
		1994 Traffic		
1. SCAN-NAM	0%	71%	13%	16%
2. EUR-NAM/EAST	0%	89%	0%	11%
3. EUR-NAM/MIDWEST	0%	39%	1%	59%
4. EUR-NAM/WEST	0%	75%	10%	15%
5. EUR,SCAN-CAR	0%	88%	12%	0%
6. IBE-USA	0%	73%	3%	23%
7. IBE-CAN	0%	43%	36%	21%
8. IBE-CAR	0%	93%	7%	0%
9. N.AFR-NAM	0%	70%	30%	0%
10. EUR-NAM/AK	0%	91%	9%	0%
11. NAM-CAR	0%	38%	41%	20%
All	0%	72%	12%	16%
		2010 Traffic		
1. SCAN-NAM	0%	80%	0%	20%
2. EUR-NAM/EAST	0%	90%	0%	10%
3. EUR-NAM/MIDWEST	0%	40%	0%	60%
4. EUR-NAM/WEST	0%	80%	0%	20%
5. EUR,SCAN-CAR	0%	90%	0%	10%
6. IBE-USA	0%	75%	0%	25%
7. IBE-CAN	0%	60%	0%	40%
8. IBE-CAR	0%	95%	0%	5%
9. N.AFR-NAM	0%	80%	0%	20%
10. EUR-NAM/AK	0%	95%	0%	5%
11. NAM-CAR	0%	60%	0%	40%
All	0%	78%	0%	22%

Table 4. North Atlantic Daily Flight Cost Savings Due to Reduced Separation Minima

Flow	Flight Cost Saving for Composite Day ($000/day) 1988	1994	2010
1. SCAN-NAM	1.12	2.96	14.67
2. EUR-NAM/EAST	41.06	49.13	107.19
3. EUR-NAM/MIDWEST	3.87	4.41	5.94
4. EUR-NAM/WEST	1.30	1.92	3.90
5. EUR,SCAN-CAR	8.24	6.04	12.53
6. IBE-USA	1.64	2.48	3.39
7. IBE-CAN	.10	.57	1.86
8. IBE-CAR	.07	.16	.52
9. N.AFR-NAM	.06	.17	.45
10.EUR-NAM/AK	.98	.73	1.29
11.NAM-CAR	5.31	7.42	15.39
All	63.76	75.99	167.15

Table 4 presents the estimated daily flight cost savings associated with the reduced separation minima. These data were derived from updates of separate Flight Cost Model analyses of baseline and ADS operations for the indicated years, and are the differences in the respective estimated daily flight costs. The analysis of baseline operations was based on the 60 nmi lateral separation minimum with variations to 90 nmi and 120 nmi where appropriate and the 10 min longitudinal separation minima with variations (9). The analysis of ADS operations was based on the 30 nmi lateral separation minimum and the 5 min longitudinal minimum with variations.

The Flight Cost Model analysis evaluated separate OTS designs representing baseline and ADS-supported lateral separation minima. The layout of the fixed routes, such as those in the western North Atlantic which connect to radionavigation aid ground sites, was the same for the OASIS baseline and ADS analyses. Also, at the time of the OASIS analysis, the fixed routes from the Iberian Peninsula toward the Caribbean did not exist. These routes have since been established to facilitate traffic management. The Flight Cost Model analysis used random routings for the Europe-Caribbean flows to represent baseline and ADS operations. These random routings would not incur costs due to any route planning restrictions associated with the fixed tracks. Since ADS-supported separation minima would afford an opportunity to restructure the fixed routes, the savings estimated for ADS could be somewhat underestimated.

The Table 4 savings represent a composite July and November day, and were derived by applying 35% weight to the July day costs and a 65% weight to the November day costs. This calculation procedure avoids over-estimating composite savings by appropriately scaling the greater congestion reductions possible in the peak summer months. The weights are based on an OASIS

analysis (7) of monthly oceanic traffic loading. Table 4 data are based on reported crew and maintenance costs by aircraft type and reported fuel cost. Crew and maintenance cost rates were estimated by applying a 5% inflation rate to those reported (14) for 1989. A fuel price of 1.00 $/gallon is used. This price represents international fuel costs reported (15) for post-August 2, 1990, which ranged from 0.80 to over 1.40 $/gallon. International fuel prices during the first seven months of 1990 reportedly (17) ranged from 0.60 to nearly 0.80 $/gallon.

The estimated annual flight cost savings corresponding to Table 4 were calculated and are summarized in Table 5. These annual estimates were derived by multiplying Table 4 daily savings for each flow and forecast year by 365 and interpolating costs for intermediate years by fitting a compound rate of growth curve for each flow. The earliest implementation of full ADS operations is assumed to be the beginning of 1995. Table 5 presents estimates of the annual costs accumulated during 1995 through 2010 in 1990 dollars.

The annual flight cost savings consist of 85% fuel cost and 15% crew and maintenance cost savings based on an analysis of OASIS Flight Cost Model data (7) for the North Atlantic. The results of applying a 5% fuel price compound annual inflation rate and a 5% crew and maintenance cost compound annual inflation rate are shown in Table 5 for each flow. The base year for compound inflation calculations is 1990. The corresponding 1990 present value savings, based on a 12% discount rate, are also shown in Table 5 for each flow. The estimated total present value saving for all years and flows is $300.3 million. This discounted value includes the inflation adjustment.

Table 5. North Atlantic Total Flight Cost Savings
Due to Reduced Separation Minima

	Cumulative Annual Flight Cost Savings 1995-2010 (US $ Millions)		
Flow	Uninflated	Inflated	1990 Present Value
1. SCAN-NAM	$44.9	$93.2	$18.3
2. EUR-NAM/EAST	$445.3	$882.4	$194.3
3. EUR-NAM/MIDWEST	$30.3	$58.3	$13.8
4. EUR-NAM/WEST	$16.7	$32.9	$7.3
5. EUR,SCAN-CAR	$53.1	$104.9	$23.3
6. IBE-USA	$17.2	$33.1	$7.8
7. IBE-CAN	$6.6	$13.4	$2.8
8. IBE-CAR	$1.9	$3.8	$.8
9. N.AFR-NAM	$1.7	$3.5	$.7
10. EUR-NAM/AK	$5.8	$11.4	$2.6
11. NAM-CAR	$65.3	$129.0	$28.6
Total	$688.8	$1,365.9	$300.3

North Atlantic Improved Oceanic ATC Flexibility Cost Impact -- Improved oceanic ATC flexibility due to ADS generates flight cost savings regardless of separation minima. These savings have not previously been quantitatively evaluated in detail based on assembled documentation. Traffic survey and related statistical data describing such impacts are not known to be available. Also, the specific ADS-based controller techniques described in the previous section of this study are informal proposals concerning operational procedures potentially implementable in the future and are subject to change. In view of the lack of available in-depth information, the flight cost impacts of improved ATC flexibility are estimated on a first-cut basis as described in the following paragraphs.

The proposed ADS-based controller techniques are means to increase ATC responsiveness to aircraft needs, especially flight level preference. In some cases, the improvements are based on the shorter time interval between ADS-based reports versus HF progress reports, which would enable a curtailment in a diversion from a preferred flight path. With respect to a potential conflict between two aircraft on crossing or reciprocal courses, the time an aircraft spends at a non-optimum flight level might be reduced by the difference between the confirmed or estimated times of establishment of proper separation in ADS versus HF operations. The magnitude of this time saving for aircraft on reciprocal courses may be equal to the applicable separation minimum as discussed in the preceding section. The magnitude of the time saving for aircraft on crossing courses would depend on the specific procedures developed for ADS operations, and could be less than the applicable separation minima. A representative potential time saving for an aircraft involved in a reciprocal or crossing potential conflict could be of the order of 5 to 10 minutes taking into account current separation rules (9) in various oceanic areas.

However, the opportunity to employ more flexible controller techniques to better resolve potential conflicts involving aircraft on reciprocal or crossing courses could be limited by traffic congestion. These techniques may be well suited to the handling of an isolated potential conflict between two aircraft, but their effectiveness may be constrained in environments involving multiple and simultaneous potential conflicts. The options available for resolving one potential conflict may be restricted by the need to maintain separation with other proximate traffic.

The ADS-based off-coarse climb technique would add to the tools available to controllers to resolve potential conflict situations. This technique's most productive application would be its use to prevent an aircraft from being trapped under another for an extended time. The off-coarse climb procedure could save several hours of non-optimum flight time for flights through the central North Atlantic where airspace is available for its implementation. This technique may be less effective in other area of the North Atlantic where traffic congestion and route structuring could inhibit its application.

Circumstance involving potential conflicts that could be better handled with ADS than HF-based controller techniques may be more likely in random route airspace than in densely-packed OTS and fixed route airspace. Subject to contrary information, this study assumes that significant benefits associated with such techniques would be realized by flights through the central North

Atlantic. The time saving attributable to ADS-based ATC flexibility is assumed to be 30 minutes for an aircraft adversely affected by a potential conflict situation. This estimate is a compromise between the 5 to 10 minute saving associated with the reciprocal and crossing course potential conflict and the several hour saving associated with the off-coarse climb technique.

Apart from potential conflict situations, eliminating the HF communication lag by ADS introduces an operational improvement. This improvement might reduce the time spent at a non-optimum flight level waiting for a step-climb approval by roughly 5 min on the average. This potential improvement would be achievable wherever ADS is implemented.

While all flows would benefit from more responsive ATC service, the impact of the service varies. Available data indicates that approximately 50% of the flights on the European flows conduct step-climbs in North Atlantic airspace (16, 18), and approximately 20% of the North America-Caribbean flights may be expected to do so (16). Definitive data describing the frequency of potential conflicts on flows through the central North Atlantic has not been obtained, a first-cut estimate is made that 10% of these flights are involved in potential conflicts subject to ADS-based improved controller intervention techniques. Based on available aircraft flight performance data, the representative incremental fuel consumption rate due to a 4000-ft diversion from a preferred flight level is roughly 1000 pounds of fuel/hour, or 2.5 gallons/min. At a fuel price of 1.00 $/gallon, the incremental cost of a 4000-ft diversion is roughly 2.50 $/min.

Tables 6 and 7 summarize the estimated flight cost savings due to ADS-based improved oceanic ATC flexibility. Table 6 shows the daily savings associated with step climbs and potential conflicts for each traffic flow and the aggregate savings. These estimates represent a composite July and November day. Table 7 shows the corresponding cumulative 1995 through 2010 cost savings with and without a 5% compound annual fuel price inflation rate, and shows the present value of the inflated cost savings based on a 12% discount rate. The estimated total present value saving for all years and traffic flows due to improved ATC flexibility is $18.2 million.

4.3 North Atlantic ADS Limitations

The estimated flight operating cost savings are subject to limitations associated with the planned area of coverage of the communication satellites and the ADS implementation plans of the ATC provider authorities.

ADS Coverage Constraints -- Based on anticipated deployment plans (6) for geostationary communication satellites, ADS geographic coverage in the northern hemisphere would be provided south of approximately the 75 degree North latitude. Allowing for adjustments in the final configuration of the satellite constellation, the assumption is made that the satellite communication coverage area will include the airspace flown by the traffic between Europe and western North America. However, the Arctic airspace is beyond the planned coverage area. Polar flights between Europe and Alaska would not be afforded ADS service, and could not achieve the cost savings theoretically possible with ADS. Flights on other traffic flows in the North Atlantic would be within the planned satellite coverage area.

Table 6. North Atlantic Daily Flight Cost Savings Due to Improved ATC Flexibility

Flow	Proportion of Flights Subject to Reduced Costs for: Step Climb	Potential Conf-lict	Estimated Daily Cost Savings ($000/day) Associated with: Step Climb 1994	Potential Conf-lict 1994	Step Climb 2010	Potential Conf-lict 2010
1. SCAN-NAM	50%	0%	$.29	$.00	$.41	$.00
2. EUR-NAM/EAST	50%	0%	$2.56	$.00	$3.51	$.00
3. EUR-NAM/MIDWEST	50%	0%	$.39	$.00	$.53	$.00
4. EUR-NAM/WEST	50%	0%	$.28	$.00	$.39	$.00
5. EUR,SCAN-CAR	50%	10%	$.29	$.35	$.39	$.47
6. IBE-USA	50%	10%	$.17	$.20	$.24	$.29
7. IBE-CAN	50%	10%	$.06	$.07	$.08	$.09
8. IBE-CAR	50%	10%	$.08	$.09	$.11	$.13
9. N.AFR-NAM	50%	10%	$.04	$.05	$.06	$.08
10.EUR-NAM/AK	50%	10%	$.14	$.17	$.20	$.24
11.NAM-CAR	20%	0%	$.50	$.00	$.69	$.00
All			$4.80	$.93	$6.60	$1.29

Flow	Estimated Daily Cost Savings ($000/day) Total 1994	Total 2010
1. SCAN-NAM	$.29	$.41
2. EUR-NAM/EAST	$2.56	$3.51
3. EUR-NAM/MIDWEST	$.39	$.53
4. EUR-NAM/WEST	$.28	$.39
5. EUR,SCAN-CAR	$.63	$.87
6. IBE-USA	$.37	$.52
7. IBE-CAN	$.12	$.17
8. IBE-CAR	$.17	$.23
9. N.AFR-NAM	$.10	$.14
10.EUR-NAM/AK	$.32	$.44
11.NAM-CAR	$.50	$.69
All	$5.73	$7.89

Table 7. North Atlantic Total Flight Cost Savings
Due to Improved ATC Flexibility

Cumulative Annual Cost Savings 1995-2010
(US $ Millions)

Flow	Uninflated	Inflated	1990 Present Value
1. SCAN-NAM	$2.1	$4.0	$.9
2. EUR-NAM/EAST	$17.9	$34.5	$8.1
3. EUR-NAM/MIDWEST	$2.7	$5.2	$1.2
4. EUR-NAM/WEST	$2.0	$3.8	$.9
5. EUR,SCAN-CAR	$4.4	$8.5	$2.0
6. IBE-USA	$2.6	$5.1	$1.2
7. IBE-CAN	$.9	$1.6	$.4
8. IBE-CAR	$1.2	$2.3	$.5
9. N.AFR-NAM	$.7	$1.3	$.3
10.EUR-NAM/AK	$2.2	$4.3	$1.0
11.NAM-CAR	$3.5	$6.7	$1.6
Total	$40.2	$77.3	$18.2

ATC Service Constraints -- ATC provider authorities have not announced plans to provide ADS service in the oceanic airspace to the south of the ADS-supported airspace currently planned (4) in the North Atlantic. Oceanic airspace jurisdictions with HF service that border the planned ADS airspace in the North Atlantic include the Piarco flight information region (FIR), SAL control area (CTA)/FIR, Dakar CTA/FIR and the Canarias FIR. The flight cost savings achievable in these circumstances would be less than 100% of those theoretically possible with ubiquitous ADS or radar services.

4.4 North Atlantic Flight Cost Saving Limitations

The impacts of ADS limitations on the North Atlantic flight cost savings due to reduced separation minima and improved ATC flexibility are estimated in the following paragraphs.

North Atlantic Reduced Separation Constraints -- Flights through ADS airspace that are bound to or from adjacent ATC jurisdictions which are without ADS or radar service would not receive the full flight cost saving benefits of ADS. The larger separation minima in such adjacent airspace would inhibit the application of reduced separation in the ADS airspace. Although reduced separation minima may be applied in ADS airspace, ADS-supported controllers would need to set-up outbound flights for the larger separation minima. The application of reduced separation minima to inbound flights could be limited by the relative positioning of these flights at ADS airspace entry.

Many of the North Atlantic flights subject to partial flight cost savings are on Caribbean routings into or out of the Piarco FIR. This FIR is south of the consolidated New York CTA/FIR and covers many southern Caribbean islands. Radar service is provided in the airspace corridor between Puerto Rico and Florida. A small gap exists between the ADS airspace of the western New York CTA/FIR and US domestic radar coverage from Puerto Rico. Assuming such gaps will be accounted for and resolved when ADS operations are established, flights in the North America-Caribbean flow on routes west of Puerto Rico or proximate to Puerto Rico would receive full ADS-supported reduced separation minima service. Based on NAT TFG data (12), about 15% of the North America-Caribbean flow is estimated to pass well east of Puerto Rico. Such flights would be on the outskirts of radar coverage or outside it. These outer flights could transition directly between ADS and HF airspace without receiving intervening radar service. In this case, they would not receive full reduced separation minima service. Although these outer flights may spend roughly 60% of their oceanic flight time in the New York CTA/FIR, the ability to apply reduced separation minima is severely limited by route congestion. Hence, the estimate is made that 15% of the flow does not receive reduced separation minima service, and the flight cost saving achievable on the overall North America-Caribbean flow is 85% of that theoretically possible with ubiquitous ADS or radar services.

Based on available traffic data (19), about one-third of the flights between the Caribbean and the Iberian Peninsula and the rest of Europe fly into or out of the Piarco FIR without receiving intervening radar service. These flights may spend roughly 90% of their oceanic flight time in ADS airspace. If reduced separation minima may be applied during two-thirds of the ADS coverage, the estimated flight cost savings achievable by this subset of flights in the flows between Europe and the Caribbean are 60% of those theoretically possible. If the remaining two-thirds of the flights receive the full theoretical saving, 87% of the theoretical savings would be achieved overall.

The results of these flight cost saving adjustments are shown in Table 8. Table 8 includes the adjustment accounting for the elimination of potential savings on the flow between Europe and Alaska due to the polar ADS coverage constraint. The adjusted estimated total present value flight cost saving due to reduced separation minima for all years and traffic flows is $290.3 million in the North Atlantic.

Table 8. North Atlantic Total Flight Cost Savings Due to Reduced Separation Minima, Adjusted for ADS Coverage and ATC Service Constraints

	Estimated 1990 Present Value Cumulative Annual Flight Cost Savings 1995-2010 (US $ Millions)		
Flow	Original Estimated Savings	ADS/ATC Adjustment Factor	Adjusted Estimated Savings
1. SCAN-NAM	$18.3	1.00	$18.3
2. EUR-NAM/EAST	$194.3	1.00	$194.3
3. EUR-NAM/MIDWEST	$13.8	1.00	$13.8
4. EUR-NAM/WEST	$7.3	1.00	$7.3
5. EUR,SCAN-CAR	$23.3	.87	$20.3
6. IBE-USA	$7.8	1.00	$7.8
7. IBE-CAN	$2.8	1.00	$2.8
8. IBE-CAR	$.8	.87	$.7
9. N.AFR-NAM	$.7	1.00	$.7
10.EUR-NAM/AK	$2.6	0.00	$.0
11.NAM-CAR	$28.6	.85	$24.3
Total	$300.3		$290.3

North Atlantic Improved ATC Flexibility Constraints -- Table 9 tabulates adjustments made to the initial estimates of flight cost savings due to ADS-based ATC flexibility improvements for the North Atlantic. The adjustments account for the proportion of flights in each traffic flow that would be beyond the ADS service or coverage limits described in the preceding paragraphs. The adjustments are calculated by prorating the previous estimates according to the proportion of oceanic flight time subject to ADS service. For example, with reference to the North America-Caribbean flow, 85% of this traffic is estimated to receive ADS or radar service benefits during all of its North Atlantic flight and 15% is estimated receive these benefits during 60% of its flight. Based on these estimates, 94% of the theoretical benefits associated with ubiquitous ADS would be obtainable on this flow. With reference to the Europe,Scandinavia-Caribbean and Iberia-Caribbean flows, two-thirds is estimated to receive ADS or radar service benefits during all of its North Atlantic flight and one-third is estimated receive these benefits during 90% of its flight. Based on these estimates, 97% of the theoretical benefits associated with ubiquitous ADS would be obtainable on this flow. The adjusted estimated total present value flight cost saving due to improved ATC flexibility for all years and traffic flows is $17.0 million in the North Atlantic.

Table 9. North Atlantic Total Flight Cost Savings Due to Improved ATC Flexibility, Adjusted for ADS Coverage and ATC Service Constraints

Estimated 1990 Present Value
Cumulative Annual Flight Cost Savings 1995-2010
(US $ Millions)

Flow	Original Estimated Savings	ADS Adjustment Factor	Adjusted Estimated Savings
1. SCAN-NAM	$.9	1.00	$.9
2. EUR-NAM/EAST	$8.1	1.00	$8.1
3. EUR-NAM/MIDWEST	$1.2	1.00	$1.2
4. EUR-NAM/WEST	$.9	1.00	$.9
5. EUR,SCAN-CAR	$2.0	.97	$1.9
6. IBE-USA	$1.2	1.00	$1.2
7. IBE-CAN	$.4	1.00	$.4
8. IBE-CAR	$.5	.97	$.5
9. N.AFR-NAM	$.3	1.00	$.3
10.EUR-NAM/AK	$1.0	0.00	$.0
11.NAM-CAR	$1.6	.94	$1.5
Total	$18.2		$17.0

5. PACIFIC OCEANIC AREA

Traffic operations and potential ADS impacts for the Pacific oceanic area are described in this section. The general operational descriptions and analyses procedures and assumptions presented in the preceding section for the North Atlantic apply to the Pacific and are not repeated in this section. This section describes aspects unique to the Pacific. Various extrapolations and approximations are made to compensate for the shortage of traffic, forecast and flight cost savings data obtained for the Pacific as opposed to the North Atlantic.

5.1 Pacific Operations

Table 10 shows commercial traffic forecasts by traffic flow group for a representative day for 1994 and 2010. These forecasts are based on FAA projections (20, 21) of annual air carrier operations to and from the US and actual daily traffic survey data (22) collected in 1984. The Table 10 traffic distributions were constructed using the FAA annual forecasts to scale and extrapolate the survey data by traffic flow. These flows are:

1. Hawaii - to/from - California (HAW - CAL)
2. Hawaii - to/from - North American Pacific Coast/Northwest (HAW - PAC/NW)
3. Hawaii - to/from - North America/Central/East, i.e., North America excluding California and the Pacific Northwest (HAW - NAM/C/E)
4. Hawaii - to/from - Asia (HAW - ASIA)
5. Hawaii - to/from - South/Central Pacific Ocean (HAW - S/C PAC)
6. Alaska - to/from - North America/West (AK - NAM/WEST)
7. Asia - to/from - Alaska (ASIA - AK)
8. Asia - to/from - North America (ASIA - NAM)
9. Asia - to/from - South/Central Pacific Ocean (ASIA - S/C PAC)
10. South/Central Pacific Ocean - to/from - North America (NAM - S/C PAC)
11. Pacific Ocean - to/from- Other Pacific Ocean Localities (PAC LOCAL)

The traffic flow designations were defined for this study to logically describe flight patterns and to conform with the formats employed by the OASIS Flight Cost Model analysis and the available traffic survey and forecast data.

<u>Central East Pacific</u> -- Oceanic flights to and from the conterminous US and Canada fly through the Pacific Ocean airspace east of Hawaii. This airspace is between the 160 degree West longitude and the North American west coast. A significant traffic flow exists between Hawaii and California and is estimated to account for 20% of the total daily flights in 1994. To accommodate this flow, the Central East Pacific Composite Route System is established. The system consists of two sets of fixed tracks with three parallel tracks in each set. A northern set runs between Hawaii and the San Francisco area and a southern set runs between Hawaii and the Los Angeles areas. The composite tracks employ a combination of lateral and vertical separation minima (9) resulting in staggered flight level assignments on adjacent routes.

Table 10. Pacific Subsonic Commercial Daily Traffic

Flow	Number of Daily Flights 1994	2010
1. HAW-CAL	111	131
2. HAW-PAC/NW	45	54
3. HAW-NAM/C/E	20	23
4. HAW-ASIA	33	78
5. HAW-S/C PAC	37	85
6. AK-NAM/WEST	27	32
7. ASIA-AK	82	189
8. ASIA-NAM	104	240
9. ASIA-S/C PAC	43	99
10. S/C PAC-NAM	15	35
11. PAC LOCAL	64	76
All	581	1042

Flights competing for preferred routes and altitudes are subject to delay and diversion at entry and while en route. Flights between Hawaii and the interior and eastern North America also use the Central East Pacific composite routes, contributing to congestion.

Flights between the Pacific Northwest and Hawaii may prefer to cross or merge with a Central East Pacific composite route depending on meteorological conditions. Two fixed routes are established to manage this traffic flow. One of the fixed routes merges with the outer composite route and the other is north of the composite route system. The Pacific Northwest flights are subject to delay and diversion due to airspace competition with each other and other flights, including those on the Central East Pacific composite routes.

The airspace north of the Central East Pacific composite routes is further congested by flights between Asia and North America, particularly California. These flights are served by a fixed route network connecting California and the Pacific Northwest with Alaska and the northern Pacific and by a flexible track system. This flexible track system is north of Hawaii and connects California and the Pacific Northwest with Japan and the northern Pacific. The flexible tracks are set twice daily based on data provided by airlines. Typically, 3 to 5 tracks are set in the morning to serve the eastbound traffic surge. A new set is established in the afternoon to serve the westbound traffic surge. The Asia-North America flow intersects the Hawaii-Pacific Northwest flow and competes for airspace with this crossing traffic and with other traffic in the Asia flow. A significant growth in the Asia-North America traffic is projected (20), accounting for 23% of the total daily traffic shown in Table 10 for 2010.

Northern Pacific -- Flights between Asia and parts of North America tend to prefer routes through the northern Pacific in the airspace corridor between Japan and Alaska. The Northern Pacific (NOPAC) Composite Route System is established to serve this traffic. It is a set of five fixed, roughly parallel routes set according to composite separation procedures. Some of the fixed routes from North America join NOPAC routes in mid-ocean. Flexible tracks from North America may approach the northern Pacific fixed routes. These route structures enable Far East flights to select routings compatible with diverse origins and destinations in North America. However, the concentration of traffic on the northern Pacific routes leads to airspace competition and delays and diversions.

Central Pacific -- A flexible track system is established for flights between Japan and Hawaii and is defined and published daily. Two tracks are normally set at any one time.

Numerous fixed routes are established to serve the diverse origins and destinations located on the south and western Pacific rim and islands in the Pacific. Fixed routes emanate from Hawaii to the south and southwest. Two fixed routes connect southern California with South Pacific islands. Fixed routes emanate from Guam in all directions. Other fixed routes connect Australia, New Zealand, various Pacific islands and Asia.

5.2 Pacific Flight Operating Cost Savings

The flight cost impacts of reduced separation minima and improved oceanic ATC flexibility in the Pacific are analogous to those of the North Atlantic.

Pacific Separation Minima Reduction Cost Impact The estimated distribution of aircraft types used in this analysis is that developed by OASIS (13). Other forecasts of aircraft fleet composition for the Pacific were not obtained. The projected fleet characteristics are similar to those for the North Atlantic. An increase in newer-generation twin-engine aircraft is assumed and the three and four engine wide-bodies, including high-altitude B747SP aircraft, are expected to extend their dominance.

Table 11 presents the estimated daily flight cost savings associated with the reduced separation minima. These estimate are updates of OASIS Flight Cost Model analysis (23) of Pacific flight operating costs. The analysis of baseline operations is based on the composite and standard lateral separation minima of 50 nmi and 100 nmi and the 10 min longitudinal separation minima with variations (9). The composite separation minima in the Pacific require a 50 nmi lateral spacing between routes and a 1000 ft vertical separation between aircraft on adjacent routes. The rules provide a 100 nmi lateral separation between aircraft at the same flight level and a 2000 ft vertical separation between aircraft on the same route. The Flight Cost Model analysis of ADS operations is based on a 25 nmi lateral separation minimum and the 5 min longitudinal minimum with variations. The OASIS results were adjusted to represent the 30 nmi lateral separation minima.

Table 11. Pacific Daily Flight Cost Savings Due to Reduced Separation Minima

Flow	Flight Cost Saving for Representative Day ($000/day) 1994	2010
1. HAW-CAL	4.61	6.25
2. HAW-PAC/NW	13.40	16.67
3. HAW-NAM/C/E	1.83	2.11
4. HAW-ASIA	2.60	6.74
5. HAW-S/C PAC	1.99	7.76
6. AK-NAM/WEST	1.01	1.27
7. ASIA-AK	3.24	11.34
8. ASIA-NAM	19.95	60.24
9. ASIA-S/C PAC	2.49	10.28
10. S/C PAC-NAM	1.51	6.09
11. PAC LOCAL	4.62	6.60
All	57.26	135.35

The Flight Cost Model analysis evaluated separate composite route system designs representing baseline and ADS-supported lateral separation minima. The layout of the non-composite fixed routes was not changed for the assessments of ADS-based operations. Also, at the time of the OASIS analysis, the fixed tracks between North America and the northern Pacific and between the Pacific Northwest and Hawaii did not exist. The Flight Cost Model analysis modeled random routes in these airspaces, and did not account for the flight route planning restrictions associated with the fixed routes and potential ADS-based route restructuring. The corresponding savings associated with ADS may be somewhat underestimated.

The OASIS Flight Cost Model analysis was restricted to the Central East Pacific. Updates of the Flight Cost Model-derived savings for traffic flows through the Central East Pacific were used, by analogous extrapolations and extensions, to estimate the savings on flows through the Pacific airspace outside the Central East Pacific.

The estimated annual flight cost savings corresponding to Table 11 are tabulated in Table 12. Table 12 presents the total estimated cost savings accumulated from 1995 through the 2010 forecast year for each traffic flow in uninflated 1990 $ million. The flight cost savings consist of 95% fuel cost and 5% crew and maintenance cost based on an analysis of OASIS data (7) for the Pacific. The cumulative results of applying a 5% fuel price compound annual inflation rate and a 5% crew and maintenance cost compound annual inflation rate are shown in Table 12 for each flow. The corresponding 1990 present value savings, based on a 12% discount rate, are also shown in Table 12 for each flow. The estimated total present value saving for all years and traffic flows is $232.1 million.

Table 12. Pacific Total Flight Cost Savings
Due to Reduced Separation Minima

Cumulative Annual Flight Cost Savings 1995-2010
(US $ Millions)

Flow	Uninflated	Inflated	1990 Present Value
1. HAW-CAL	$31.8	$61.1	$14.4
2. HAW-PAC/NW	$88.1	$168.5	$40.3
3. HAW-NAM/C/E	$11.5	$22.0	$5.3
4. HAW-ASIA	$26.2	$52.4	$11.3
5. HAW-S/C PAC	$25.8	$52.9	$10.7
6. AK-NAM/WEST	$6.7	$12.8	$3.1
7. ASIA-AK	$39.3	$80.0	$16.5
8. ASIA-NAM	$220.4	$445.1	$93.6
9. ASIA-S/C PAC	$33.5	$68.9	$13.9
10. S/C PAC-NAM	$20.0	$41.2	$8.3
11. PAC LOCAL	$32.8	$63.2	$14.8
Total	$536.0	$1,068.2	$232.1

Pacific Improved Oceanic ATC Flexibility Cost Impact -- Available data (23) indicates that approximately 60% of the flights conduct step-climbs in Pacific airspace. The assumption is made that 10% of flights on non-composite routes are involved in potential conflicts subject to ADS-based improved controller intervention techniques. Tables 13 and 14 summarize the estimated flight cost savings due to ADS-based improved oceanic ATC flexibility. Table 13 shows the daily savings associated with step climbs and potential conflicts for each traffic flow and the aggregate savings. Table 14 shows the corresponding cumulative 1995 through 2010 cost savings with and without a 5% compound annual fuel price inflation rate, and shows the present value of the inflated cost savings based on a 12% discount rate. The estimated total present value saving for all years and traffic flows due to improved ATC flexibility is $27.1 million.

Table 13. Pacific Daily Flight Cost Savings Due to Improved ATC Flexibility

Flow	Proportion of Flights Subject to Reduced Costs for: Step Climb	Potential Conf-lict	Estimated Daily Cost Savings ($000/day) Associated with: Step Climb 1994	Potential Conf-lict 1994	Step Climb 2010	Potential Conf-lict 2010
1. HAW-CAL	60%	0%	$.83	$.00	$.98	$.00
2. HAW-PAC/NW	60%	10%	$.34	$.34	$.41	$.41
3. HAW-NAM/C/E	60%	10%	$.15	$.15	$.17	$.17
4. HAW-ASIA	60%	10%	$.25	$.25	$.59	$.59
5. HAW-S/C PAC	60%	10%	$.28	$.28	$.64	$.64
6. AK-NAM/WEST	60%	10%	$.20	$.20	$.24	$.24
7. ASIA-AK	60%	0%	$.61	$.00	$1.42	$.00
8. ASIA-NAM	60%	10%	$.78	$.78	$1.80	$1.80
9. ASIA-S/C PAC	60%	10%	$.32	$.32	$.74	$.74
10. S/C PAC-NAM	60%	10%	$.11	$.11	$.26	$.26
11. PAC LOCAL	60%	10%	$.48	$.48	$.57	$.57
All			$4.36	$2.91	$7.82	$5.42

Flow	Estimated Daily Cost Savings ($000/day) Total 1994	Total 2010
1. HAW-CAL	$.83	$.98
2. HAW-PAC/NW	$.68	$.81
3. HAW-NAM/C/E	$.30	$.35
4. HAW-ASIA	$.50	$1.17
5. HAW-S/C PAC	$.56	$1.28
6. AK-NAM/WEST	$.41	$.48
7. ASIA-AK	$.61	$1.42
8. ASIA-NAM	$1.56	$3.60
9. ASIA-S/C PAC	$.65	$1.49
10. S/C PAC-NAM	$.23	$.53
11. PAC LOCAL	$.96	$1.14
All	$7.27	$13.23

Table 14. Pacific Total Flight Cost Savings Due to Improved ATC Flexibility

Cumulative Annual Cost Savings 1995-2010 (US $ Millions)

Flow	Uninflated	Inflated	1990 Present Value
1. HAW-CAL	$5.3	$10.2	$2.4
2. HAW-PAC/NW	$4.4	$8.3	$2.0
3. HAW-NAM/C/E	$1.9	$3.6	$.9
4. HAW-ASIA	$5.0	$9.9	$2.2
5. HAW-S/C PAC	$5.5	$10.8	$2.4
6. AK-NAM/WEST	$2.6	$5.0	$1.2
7. ASIA-AK	$6.1	$12.0	$2.7
8. ASIA-NAM	$15.4	$30.6	$6.7
9. ASIA-S/C PAC	$6.4	$12.6	$2.8
10. S/C PAC-NAM	$2.2	$4.4	$1.0
11. PAC LOCAL	$6.2	$11.8	$2.8
Total	$60.9	$119.2	$27.1

5.3 Pacific ADS Limitations

Assessment of flight cost saving limitations require consideration of ADS coverage and implementation plans pertinent to the Pacific.

<u>ADS Coverage Constraints</u> -- The Pacific traffic flows would be within the planned satellite coverage area, and flight cost savings would not be constrained by ADS coverage.

<u>ATC Service Constraints</u> -- ATC provider authorities have not announced plans to provide ADS service in the oceanic airspace immediately adjacent to the ADS-supported airspace currently planned (4) by the US and Japan in the Pacific. Oceanic airspaces that currently border this planned ADS airspace in the Pacific include the Tahiti oceanic control area (OCA)/FIR, Nadi OCA/FIR, Port Moresby FIR, Biak FIR, Ujung Pandang upper information region, Manila OCA/FIR, and uncontrolled airspaces near Honiara and Mazatlan jurisdictions.

5.4 Pacific Flight Cost Saving Limitations

The impacts of ADS limitations on the Pacific flight cost savings due to reduced separation minima and improved ATC flexibility are estimated in the following paragraphs.

Pacific Reduced Separation Minima Constraints -- Flights in flows between the South/Central Pacific and Hawaii and North America may spend roughly 50% of their oceanic flight time in ADS airspace. If reduced separation minima may be applied during two-thirds of the ADS coverage, the estimated flight cost savings achievable on these flows are one-third of those theoretically possible. Similarly, flights in the Asia-South/Central Pacific flow may spend roughly 75% of their oceanic flight time in ADS airspace, resulting in an estimated achievable flight cost saving of 50% of that theoretically possible. The results of these flight cost saving adjustments are included in Table 15. The adjusted estimated total present value flight cost saving due to reduced separation minima for all years and traffic flows is and $212.4 million in the Pacific.

Table 15. Pacific Total Flight Cost Savings Due to Reduced Separation Minima, Adjusted for ADS Coverage and ATC Service Constraints

	Estimated 1990 Present Value Cumulative Annual Flight Cost Savings 1995-2010 (US $ Millions)		
Flow	Original Estimated Savings	ADS/ATC Adjustment Factor	Adjusted Estimated Savings
1. HAW-CAL	$14.4	1.00	$14.4
2. HAW-PAC/NW	$40.3	1.00	$40.3
3. HAW-NAM/C/E	$5.3	1.00	$5.3
4. HAW-ASIA	$11.3	1.00	$11.3
5. HAW-S/C PAC	$10.7	.33	$3.5
6. AK-NAM/WEST	$3.1	1.00	$3.1
7. ASIA-AK	$16.5	1.00	$16.5
8. ASIA-NAM	$93.6	1.00	$93.6
9. ASIA-S/C PAC	$13.9	.50	$6.9
10. S/C PAC-NAM	$8.3	.33	$2.7
11. PAC LOCAL	$14.8	1.00	$14.8
Total	$232.1		$212.4

Pacific Improved ATC Flexibility Constraints -- Table 16 tabulates adjustments made to the initial estimates of flight cost savings due to ADS-based ATC flexibility improvements for the Pacific. With reference to the Hawaii-South/Central Pacific and South Central Pacific-North America flows, ADS service benefits are estimated to be received during 50% the Pacific flight. With reference to the Asia-South/Central Pacific flow, ADS service benefits are estimated to be received during 75% the Pacific flight. The adjusted estimated total present value flight cost saving due to improved ATC flexibility for all years and traffic flows is $24.7 million in the Pacific.

Table 16. Pacific Total Flight Cost Savings Due to Improved ATC Flexibility, Adjusted for ADS Coverage and ATC Service Constraints

	Estimated 1990 Present Value Cumulative Annual Flight Cost Savings 1995-2010 (US $ Millions)		
Flow	Original Estimated Savings	ADS Adjustment Factor	Adjusted Estimated Savings
1. HAW-CAL	$2.4	1.00	$2.4
2. HAW-PAC/NW	$2.0	1.00	$2.0
3. HAW-NAM/C/E	$.9	1.00	$.9
4. HAW-ASIA	$2.2	1.00	$2.2
5. HAW-S/C PAC	$2.4	.50	$1.2
6. AK-NAM/WEST	$1.2	1.00	$1.2
7. ASIA-AK	$2.7	1.00	$2.7
8. ASIA-NAM	$6.7	1.00	$6.7
9. ASIA-S/C PAC	$2.8	.75	$2.1
10. S/C PAC-NAM	$1.0	.50	$.5
11. PAC LOCAL	$2.8	1.00	$2.8
Total	$27.1		$24.7

6. AIR-GROUND COMMUNICATION USER COST

The costs incurred by air-ground communication system users are estimated in this section. User costs are estimated for two alternatives:

- o Continuance of the baseline HF voice system through the year 2010.
- o Implementation of the satellite-based ADS data link system in 1995.

Initial estimates of user costs are made based on informal consultations with communications industry specialists. The ADS cost estimates are then adjusted to account for anticipated ADS service limitations.

6.1 Baseline HF Air-Ground Communication User Cost

The aggregate charge for using the baseline HF air-ground voice communications system to send and receive ATC and other air traffic service messages in the US North Atlantic and Pacific airspace is estimated (11) to be $10 million annually. This estimate includes an allowance for on-going HF voice communication system development activities. Data was not obtained describing user charges in non-US oceanic airspaces. The assumption is made that the scale of the US operation is roughly half that of the overall oceanic HF voice communication service in the North Atlantic and Pacific airspace subject to planned ADS implementation. This ADS airspace excludes the northern polar area and the southerly North Atlantic and Pacific areas. Hence, the first-cut estimate is made that the cost recovery requirement of the baseline HF voice system for air traffic services communications totals $20 million annually for the North Atlantic and Pacific airspace under study. This estimate does not allow for any additional expenditures which may be required to further expand the HF communication system in response to traffic growth during 1990 through 2010. Data has not been obtained addressing expansion requirements and costs.

6.2 ADS Air-Ground Communication User Cost and Limitations

Informal consultations indicate that ADS air-ground communication system recovery costs may be only roughly estimated because of uncertainties concerning future operational requirements and technical implementations. However, preliminary estimates (24) of satellite communication user charges have been provided. Based in part on these estimates and in part on the possibility that additional cost accounting may be required for network distribution and other support requirements, a first-cut approximation of the user charge for satellite data link communications with low gain antennae is $1.20 per kilobit transmitted. This estimate may be conservatively high for a fully developed operational system.

A basic ADS report transaction is assumed to require one-half kilobit, including transmission management and message integrity protection overhead. This assumption is based on available data (1, 6) describing message size characteristics, including interrogation requirements. An estimate of $0.60 per message transaction for a basic ADS report results. Transmitting at a faster character rate with high gain antennae would reduce the user message charge.

Basic ADS reports would be made at 5 min intervals in oceanic airspace. Other ADS messages of various durations would be transmitted to and from various oceanic flights. To account for the other messages, the assumption is made that the total message loading is equivalent to a 10% increase in the number of basic ADS reports.

These estimates may be used to evaluate ADS communication system user charges by traffic flow for the North Atlantic and Pacific.

North Atlantic ADS Air-Ground Communication User Charges -- As an example of the procedure used to estimate user charges, consider the traffic flow between eastern North America and Europe. A representative flight in this flow is estimated to spend 3 hours in the oceanic airspace between Newfoundland and the British Isles based on an assumed 480 nmi/hour cruising speed and the route length. The representative route length is the calculated great circle distance between typical oceanic entry and exit points for this flow. Assuming basic ADS reports are issued at 5 minute intervals and at oceanic entry and exit, 37 basic ADS reports would be transmitted. A total loading estimate of 41 ADS message transactions is obtained by increasing the number of basic ADS reports by 10% to account for other messages. Applying the estimated message unit charge rate results in $24.60 per flight for ADS operations with low gain antennae.

The results of similar calculations are shown in Table 17. Table 17 shows the user charges associated with the representative flight for each North Atlantic traffic flow. Table 17 also shows the corresponding daily user charge by traffic flow for 1994 and 2010, assuming 100% ADS fleet equipage with low gain antennae.

A pre-operational system shakedown is assumed to occur in 1993 and 1994 during which ADS-equipped aircraft would intermittently participate in data link tests. The assumption is made that the annual user charges for ADS service during the shakedown period would be 10% of the user charges that would have been incurred if ADS was fully operational in 1994. Annual user charges based directly on interpolations of the Table 17 daily cost estimates are assumed to be incurred in 1995 and thereafter. Table 18 shows the resulting cumulative 1993 through 2010 estimated user charges by North Atlantic traffic flow. Table 18 shows the user charges with and without a 5% compound annual inflation rate and shows the present value of the inflated charges based on a 12% discount rate.

Table 17. North Atlantic Daily ADS Communication Message User Costs

Flow	Oceanic Flight Length (nmi)	Oceanic Flight Time (hours)	Number of Messages per Flight	User Charges per Flight ($/flt)	Estimated Daily User Charges ($000/day) 1994	2010
	Representative Oceanic Flight					
1. SCAN-NAM	1535	3.20	43	$25.80	$1.21	$1.68
2. EUR-NAM/EAST	1440	3.00	41	$24.60	$10.09	$13.83
3. EUR-NAM/MIDWEST	1440	3.00	41	$24.60	$1.53	$2.09
4. EUR-NAM/WEST	1580	3.29	45	$27.00	$1.22	$1.67
5. EUR,SCAN-CAR	3070	6.40	86	$51.60	$2.37	$3.25
6. IBE-USA	1970	4.10	55	$33.00	$.89	$1.25
7. IBE-CAN	1620	3.38	46	$27.60	$.25	$.33
8. IBE-CAR	2670	5.56	75	$45.00	$.54	$.77
9. N.AFR-NAM	1970	4.10	55	$33.00	$.23	$.33
10.EUR-NAM/AK	2750	5.73	77	$46.20	$1.06	$1.48
11.NAM-CAR	960	2.00	28	$16.80	$3.36	$4.60
					$22.75	$31.28

Table 18. North Atlantic Total ADS Communication Message User Charges

Flow	Cumulative Annual User Charges 1993-2010 (US $ Millions) Uninflated	Inflated	1990 Present Value
1. SCAN-NAM	$8.6	$16.5	$3.9
2. EUR-NAM/EAST	$71.2	$136.6	$32.6
3. EUR-NAM/MIDWEST	$10.8	$20.7	$4.9
4. EUR-NAM/WEST	$8.6	$16.5	$3.9
5. EUR,SCAN-CAR	$16.8	$32.1	$7.7
6. IBE-USA	$6.4	$12.3	$2.9
7. IBE-CAN	$1.7	$3.3	$.8
8. IBE-CAR	$3.9	$7.5	$1.8
9. N.AFR-NAM	$1.7	$3.2	$.8
10.EUR-NAM/AK	$7.6	$14.5	$3.5
11.NAM-CAR	$23.7	$45.5	$10.9
Total	$161.0	$306.6	$73.7

Pacific ADS Air-Ground Communication User Charges -- The ADS communication system user charges estimated for the Pacific are tabulated in Tables 19 and 20. Table 19 shows the user charges associated with the representative flight for each Pacific traffic flow. Table 19 also shows the corresponding daily user charge by traffic flow for 1994 and 2010, assuming 100% ADS fleet equipage with low gain antennae. Table 20 shows the cumulative 1993 through 2010 user charges by flow, including pre-operational shakedown. Table 20 shows the charges with and without a 5% compound annual inflation rate and shows the present value of the inflated charges based on a 12% discount rate.

Table 19. Pacific Daily ADS Communication Message User Costs

Flow	Representative Oceanic Flight: Oceanic Flight Length (nmi)	Oceanic Flight Time (hours)	Number of Messages per Flight	User Charges per Flight ($/flt)	Estimated Daily User Charges ($000/day) 1994	2010
1. HAW-CAL	1770	3.69	50	$30.00	$3.33	$3.93
2. HAW-PAC/NW	1950	4.06	55	$33.00	$1.49	$1.78
3. HAW-NAM/C/E	1770	3.69	50	$30.00	$.60	$.69
4. HAW-ASIA	2875	5.99	80	$48.00	$1.58	$3.74
5. HAW-S/C PAC	3625	7.55	101	$60.60	$2.24	$5.15
6. AK-NAM/WEST	1295	2.70	37	$22.20	$.60	$.71
7. ASIA-AK	2415	5.03	68	$40.80	$3.35	$7.71
8. ASIA-NAM	3980	8.29	111	$66.60	$6.93	$15.98
9. ASIA-S/C PAC	3105	6.47	86	$51.60	$2.22	$5.11
10. S/C PAC-NAM	5365	11.18	149	$89.40	$1.34	$3.13
11. PAC LOCAL	2020	4.21	57	$34.20	$2.19	$2.60
					$25.86	$50.54

Table 20. Pacific Total ADS Communication Message User Charges

Cumulative Annual User Charges 1993-2010
(US $ Millions)

Flow	Uninflated	Inflated	1990 Present Value
1. HAW-CAL	$21.6	$40.9	$10.0
2. HAW-PAC/NW	$9.7	$18.4	$4.5
3. HAW-NAM/C/E	$3.8	$7.3	$1.8
4. HAW-ASIA	$16.1	$31.3	$7.0
5. HAW-S/C PAC	$22.3	$44.0	$9.8
6. AK-NAM/WEST	$3.9	$7.4	$1.8
7. ASIA-AK	$33.3	$65.8	$14.6
8. ASIA-NAM	$69.1	$136.4	$30.3
9. ASIA-S/C PAC	$22.1	$43.6	$9.7
10. S/C PAC-NAM	$13.5	$26.6	$5.9
11. PAC LOCAL	$14.2	$27.0	$6.6
Total	$229.5	$449.2	$102.0

<u>ADS Air-Ground Communication User Charge Limitations</u> -- ADS air-ground communication charges would not be levied in airspaces where ADS communications are not conducted. HF air-ground voice communication would continue to be used in such airspaces. Adjustments to the initial estimates of ADS communication system user charges are required to account for ADS limitations. Tables 21 and 22 tabulate such adjustments for the North Atlantic and Pacific respectively. The adjustments are calculated by prorating the initial cost estimates according to the proportion of oceanic flight time spent in ADS versus HF airspace by the representative flight for the applicable traffic flow.

The representative flight used to evaluate communication charges is assumed to fly a route typical of most flights in the traffic flow. As a result, the representative route constructed for each North Atlantic flow, except the Europe-Alaska flow, is such that ADS service is provided for its entire oceanic flight. Adjustments are not necessary for the communication user charges except for the Europe-Alaska flow. This polar flow would not be within the planned coverage of satellite data link communication service, and would not be subject to ADS communication user charges. The corresponding adjustment is shown in Table 21 for the North Atlantic.

Table 21. North Atlantic Total ADS Communication Message User Charges Adjusted for ADS Versus HF Service Use

	Estimated 1990 Present Value Cumulative Annual User Charge 1993-2010 (US $ Millions)		
Flow	Original Estimated Costs	ADS/HF Adjustment Factor	Adjusted Estimated Costs
1. SCAN-NAM	$3.9	1.00	$3.9
2. EUR-NAM/EAST	$32.6	1.00	$32.6
3. EUR-NAM/MIDWEST	$4.9	1.00	$4.9
4. EUR-NAM/WEST	$3.9	1.00	$3.9
5. EUR,SCAN-CAR	$7.7	1.00	$7.7
6. IBE-USA	$2.9	1.00	$2.9
7. IBE-CAN	$.8	1.00	$.8
8. IBE-CAR	$1.8	1.00	$1.8
9. N.AFR-NAM	$.8	1.00	$.8
10.EUR-NAM/AK	$3.5	0.00	$.0
11.NAM-CAR	$10.9	1.00	$10.9
Total	$73.7		$70.2

With reference to the representative routes for the Hawaii-South/Central Pacific and South Central Pacific-North America flows, ADS coverage is estimated to be provided during 50% of the Pacific flight. With reference to the representative route for the Asia-South/Central Pacific flow, ADS coverage is estimates to be provided during 75% of the Pacific flight. The corresponding adjustments are shown in Table 22 for the Pacific.

Table 22. Pacific Total ADS Communication Message User Charges Adjusted for ADS Versus HF Service Use

	Estimated 1990 Present Value Cumulative Annual User Charge 1993-2010 (US $ Millions)		
Flow	Original Estimated Costs	ADS/HF Adjustment Factor	Adjusted Estimated Costs
1. HAW-CAL	$10.0	1.00	$10.0
2. HAW-PAC/NW	$4.5	1.00	$4.5
3. HAW-NAM/C/E	$1.8	1.00	$1.8
4. HAW-ASIA	$7.0	1.00	$7.0
5. HAW-S/C PAC	$9.8	.50	$4.9
6. AK-NAM/WEST	$1.8	1.00	$1.8
7. ASIA-AK	$14.6	1.00	$14.6
8. ASIA-NAM	$30.3	1.00	$30.3
9. ASIA-S/C PAC	$9.7	.75	$7.3
10. S/C PAC-NAM	$5.9	.50	$3.0
11. PAC LOCAL	$6.6	1.00	$6.6
Total	$102.0		$91.7

The adjusted total present values of the ADS communication system user charges estimated for all years and traffic flows are $70.2 million for the North Atlantic and 91.7 for the Pacific, which total $161.9 million.

6.3 ADS Air-Ground Communication User Cost Increase

The air-ground communication user cost estimates are tabulated separately in Table 23 for the baseline HF system and the ADS system. Table 23 includes certain cost items pertaining to ADS implementation considerations which are explained in the following paragraphs. The annual costs shown for the years 1990 through 2020 are in uninflated, undiscounted dollars. Table 23 also shows the total costs accumulated over all these years with and without a 5% compound annual inflation rate, and shows the present value of the inflated total user costs based on a 12% compound annual discount rate.

Table 23. Air-Ground Communication Message User Costs by System

User Costs ($ million)

Year	Baseline System HF Service	ADS System: ADS Service Charges: North Atlantic	ADS Service Charges: Pacific	ADS Service Charges: ADS Subtotal	HF Support Service	Total	ADS Cost Increase
1990	$20.00	$.00	$.00	$.00	$20.00	$20.00	$.00
1991	$20.00	$.00	$.00	$.00	$20.00	$20.00	$.00
1992	$20.00	$.00	$.00	$.00	$20.00	$20.00	$.00
1993	$20.00	$.79	$.86	$1.65	$20.00	$21.65	$1.65
1994	$20.00	$.79	$.86	$1.65	$20.00	$21.65	$1.65
1995	$20.00	$8.10	$9.08	$17.18	$16.00	$33.18	$13.18
1996	$20.00	$8.28	$9.57	$17.85	$16.00	$33.85	$13.85
1997	$20.00	$8.47	$10.06	$18.53	$16.00	$34.53	$14.53
1998	$20.00	$8.66	$10.55	$19.21	$.00	$19.21	($.79)
1999	$20.00	$8.84	$11.05	$19.89	$.00	$19.89	($.11)
2000	$20.00	$9.03	$11.54	$20.57	$.00	$20.57	$.57
2001	$20.00	$9.21	$12.03	$21.24	$.00	$21.24	$1.24
2002	$20.00	$9.40	$12.53	$21.93	$.00	$21.93	$1.93
2003	$20.00	$9.58	$13.02	$22.60	$.00	$22.60	$2.60
2004	$20.00	$9.77	$13.51	$23.28	$.00	$23.28	$3.28
2005	$20.00	$9.95	$14.00	$23.95	$.00	$23.95	$3.95
2006	$20.00	$10.14	$14.50	$24.64	$.00	$24.64	$4.64
2007	$20.00	$10.32	$14.99	$25.31	$.00	$25.31	$5.31
2008	$20.00	$10.51	$15.48	$25.99	$.00	$25.99	$5.99
2009	$20.00	$10.69	$15.98	$26.67	$.00	$26.67	$6.67
2010	$20.00	$10.88	$16.47	$27.35	$.00	$27.35	$7.35
Total	$420.0	$153.4	$206.1	$359.5	$148.0	$507.5	$87.5

	Baseline System HF Service	ADS System: ADS Service Charges: North Atlantic	ADS Service Charges: Pacific	ADS Service Charges: ADS Subtotal	HF Support Service	Total	ADS Cost Increase
Total Cost with Inflation:	$714.4	$294.1	$403.0	$697.1	$170.9	$868.0	$153.6
1990 Present Value of Inflated Cost:	$237.5	$70.2	$91.7	$161.9	$116.9	$278.8	$41.3

The present value total user cost associated with continuance of the baseline HF system during 1990 through 2010 is $237.5 million.

The ADS cost estimates assume that shakedown test costs would be incurred in 1993 and 1994, and that satellite data link service would be fully operational at the start of 1995 with 100% ADS aircraft fleet equipage. The ADS service charges shown in Table 23 reflect these assumptions. The HF air-ground voice communication system would be fully employed prior to 1995. Therefore, the annual $20 million user cost of the HF system is assigned to the ADS implementation alternative during 1990 through 1994. To account for ADS implementation transition, the assumption is made that the HF system would be maintained for support in parallel with ADS for three years during 1995 through 1997. However, given the assumption that full satellite data link service would be provided in 1995, a full system-wide HF operational capability is not expected to be required during this transition period. Subject to technical and operational feasibility considerations, a lower cost HF system might be used. Labor costs reportedly (11) account for 40% of the US HF system cost. The assumption is made that HF costs may be reduced by 20% annually during the transition period, which accounts for the $16 million cost for HF services shown in Table 23 for the ADS alternative during 1995 through 1997. The resulting present value total user cost associated with ADS air-ground communication implementation in 1995 is $278.8 million.

The present value of the ADS air-ground communication total user cost increase estimated for 1990 through 2010, relative to continuance of the HF baseline system, is $41.3 million.

7. ADS AIRCRAFT COMMUNICATION EQUIPMENT COST

ADS implementation will require expenditures by aircraft operators to purchase satellite data link communication equipment and install the equipment on the aircraft fleet. The aircraft equipage cost will depend on the unit price of the equipment, the number of aircraft in the ADS fleet, including the number subject to retrofit installation, and maintenance requirements. The ADS aircraft equipage costs are estimated in this section.

7.1 ADS Aircraft Equipment Unit Cost

Satellite communications equipment installed on-board aircraft may include low gain or high gain antenna. ADS functions are supported by both type of antenna. The equipment purchase cost of an on-board ADS communication system with a low gain antenna is expected to be less than half that of one with a high gain antenna based on the following estimates provided by the FAA Technical Center:

Satellite Communication Unit	$ 80,000
Data Management Unit	$ 25,000
ADS Unit	$ 15,000
Low Gain Antenna	$ 17,000
Purchase Cost	$137,000

The $15,000 estimate for the ADS unit assumes the unit integrates the ADS data and message processing functions with an existing flight management system or other existing avionics. An alternative stand-alone unit which provides the ADS functions without other support is estimated to cost $35,000. A high gain antenna is estimated to cost $180,000.

Informal estimates (11) indicate the cost of a retrofit installation of the communication equipment on an existing aircraft could range from $75,000 to $100,000, and the incremental cost of placing the equipment on a new aircraft prior to initial delivery would not be significant. The resulting estimated 1990 acquisition cost for an on-board ADS communications system with a low gain antenna is:

	New Delivery	Retrofit
Purchase Cost	$137,000	$137,000
Installation Cost		$100,000
Total Cost per Aircraft	$137,000	$237,000

The annual maintenance cost for aircraft equipment is estimated (6) to be 6% of the total installed equipment cost. The corresponding annual maintenance cost would be $14,200 per aircraft based on the purchase and installation cost for a retrofit.

The low gain antennae also support satellite-based airline administrative communications and airline operational communications. Airline downlink messages reportedly (11) would include aircraft maintenance discrepancy, engine health monitoring, delay, estimated time of arrival, information request, and weather/wind/turbulence data; and, uplink messages would include clock update, dispatch release and reclearance, flight plan and route, gate assignment, passenger information, voice request, weather, and weight and balance/load manifest data. Such data link communications currently are conducted in domestic airspace to enhance company operating efficiency. These messages are internal to airline operations and are not an air traffic services function, and their benefits are attributable to satellite communication, not ADS. Hence, the assessment of airline company communications is outside the scope of this study, and the evaluation of their cost savings is not pertinent to ADS assessment. Since the benefits to company communications are excluded, an accounting should also made of the corresponding implementation costs. Lacking specific data, the first-cut assumption is made that 50% of the transmissions possible with low gain antenna are airline administrative and operational communications. Therefore, 50% of the costs for the on-board communication equipment with low gain antennae are allocated to ADS as follows:

	ADS Allocation	
	New Delivery	Retrofit
Purchase Cost	$68,500	$68,500
Installation Cost		$50,000
Total Cost per Aircraft	$68,500	$118,500
Annual Maintenance Cost per Aircraft	$7,100	$7,100

Although low gain antenna would support ADS and other data link message transmission functions, many aircraft operators are expected (25) to install high gain antennae. The high gain antennae will provide air-ground digital voice communication. This capability could be a useful additional ATC feature in certain situations, such as emergencies, where direct pilot-controller voice contact would be helpful.

An aircraft operators' interest in installing high gain antennae presumably is based on considerations beyond ADS. Satellite-based digital voice communications, for example, could be provided as a pubic correspondence service to passengers. This mobile telephone service might be a potentially significant revenue generator. Since the additional benefits of high gain antennae are not associated with ADS, the additional cost of the high gain antennae should not be attributed to ADS. Assuming ADS operations may be performed with low gain antennae, only low gain system costs are considered relevant to the ADS benefit and cost analysis. Therefore, the cost estimate allocations for each on-board ADS communication system are limited to the purchase and installation and annual maintenance costs previously estimated for the low gain system.

An alternative procedure for allocating the high gain system costs could be based on the relative proportional use of the satellite communication service for ADS versus non-ADS functions. Given the large number of business passengers carried on oceanic aircraft, the message loading volume of public correspondence conceivably may far exceed that of ADS. If costs were allocated according to usage proportion, significantly less of the high gain system costs might be attributed to ADS than the cost allocation described in the previous paragraphs.

7.2 ADS Aircraft Fleet Size

With reference to Tables 2 and 10, a total of 1564 daily one-way, non-stop oceanic flights is estimated for the North Atlantic and Pacific in the 1994 peak summer season. The number of oceanic flights conducted by one aircraft in one day depends on aircraft route assignment and scheduling practices of operators, departure times, flight lengths, turn-around times and related factors. If the assumption is made that half the aircraft fleet makes one roundtrip daily and the remainder makes one daily one-way trip, 521 aircraft would make two oceanic flights daily and 522 aircraft would make one oceanic flight daily. A total of 1043 aircraft would be required daily.

The number of aircraft requiring equipment installation to provide a 100% ADS fleet capability each day depends on the ability to have aircraft available for daily oceanic service. The availability depends on aircraft route assignment and scheduling strategies, out-of-service occurrences, and the like. To account for these factors as well as schedule variations, military and general aviation equipages, and the traffic growth from mid-1994 to the start of 1995, the assumption is made that the base number of aircraft required in the ADS fleet should be increased by 15% to provide 100% ADS equipage in daily oceanic operations. A total of 1200 aircraft fitted with ADS communication equipment would be required by the start of 1995.

Another approach for estimating equipage requirements may be based on fleet size statistics. The estimated size of the 1989 worldwide commercial jet fleet is 8302 aircraft as reported by a market analysis (26). This market analysis forecasts 3561 new aircraft deliveries and 1587 retirements during the years 1990 through 1994. The resulting estimated worldwide commercial jet fleet size for the start of 1995 is 10,276 aircraft. An estimate (6) of the proportion of aircraft in transoceanic service is 12% and the proportion in polar service is 4%. The corresponding estimates of the number of candidates for ADS equipage worldwide by 1995 would be 1233 aircraft in transoceanic service and 1644 aircraft if polar service is included. Because these values represent worldwide projections, they may be overestimates of commercial fleet requirements for the North Atlantic and Pacific ADS operations.

Alternatively, a recent forecast (27) estimates that 832 aircraft may be equipped with satellite communication by 1995, and 1302 aircraft by 1996. This forecast was based on an analysis of aircraft operator plans and expectations.

The initial estimated requirement for 1200 aircraft equipages by 1995 is between the other two estimates, and appears to be an appropriate representation of 100% fleet equipage requirements.

7.3 ADS Aircraft Fleet Equipage Cost

The total daily traffic in the North Atlantic and Pacific is estimated to increase from 1564 flights in 1994 to 2389 flights in 2010 based on the forecasts in Tables 2 and 10 for the peak season July day. Using 1200 ADS-equipped aircraft at the start of 1995 as a base and assuming a 53% increase, a requirement for 1840 ADS-equipped aircraft in 2010 is estimated. This is an increase of 640 aircraft over the 100% ADS fleet size requirement estimated for the start of 1995.

Table 24 summarizes the 100% ADS fleet equipage costs corresponding to the fleet size estimates and the unit cost estimates for the low gain system. The cost estimates in Table 24 assume the original 1200 aircraft are outfitted with satellite data link communication equipment during 1990 through 1994. The equipage schedule is based on an estimate (11) of ADS-equipped new deliveries which projects 300 such aircraft by 1995 and a total of 500 by the year 2000. To conform with this estimate, 900 retrofit installations would be required by 1995. New deliveries, at a rate of 40 per year, would account for the ADS equipage requirements in 1995 and thereafter. Maintenance costs are assumed to be incurred annually during 1990 through 2010. Table 24 shows total costs accumulated during 1990 through 2010 with and without a 5% compound annual inflation rate for purchase and installation expenses and a 5% compound annual inflation rate for maintenance expenses. Table 24 also shows the present value of the inflated costs based on a 12% discount rate. The present value of the total costs accumulated through 2010 for all on-board ADS communication equipment is $213.2 million.

Table 24. Aircraft ADS Communication Equipment Costs

	Annual Number of Aircraft			Equipment Cost ($ million)		
Year	New	Retro-fit	Total	Purchase & Install	Mainte-nance	Total
1990	5.0	.0	5.0	$.34	$.04	$.38
1991	70.0	.0	70.0	$4.80	$.53	$5.33
1992	75.0	.0	75.0	$5.14	$1.07	$6.20
1993	75.0	400.0	475.0	$52.54	$4.44	$56.98
1994	75.0	500.0	575.0	$64.39	$8.52	$72.91
1995	40.0	.0	40.0	$2.74	$8.80	$11.54
1996	40.0	.0	40.0	$2.74	$9.09	$11.83
1997	40.0	.0	40.0	$2.74	$9.37	$12.11
1998	40.0	.0	40.0	$2.74	$9.66	$12.40
1999	40.0	.0	40.0	$2.74	$9.94	$12.68
2000	40.0	.0	40.0	$2.74	$10.22	$12.96
2001	40.0	.0	40.0	$2.74	$10.51	$13.25
2002	40.0	.0	40.0	$2.74	$10.79	$13.53
2003	40.0	.0	40.0	$2.74	$11.08	$13.82
2004	40.0	.0	40.0	$2.74	$11.36	$14.10
2005	40.0	.0	40.0	$2.74	$11.64	$14.38
2006	40.0	.0	40.0	$2.74	$11.93	$14.67
2007	40.0	.0	40.0	$2.74	$12.21	$14.95
2008	40.0	.0	40.0	$2.74	$12.50	$15.24
2009	40.0	.0	40.0	$2.74	$12.78	$15.52
2010	40.0	.0	40.0	$2.74	$13.06	$15.80
All	940	900	1840	$171.0	$189.5	$360.6

	Purchase & Install	Mainte-nance	Total
Cost with Inflation:	$232.9	$356.2	$589.1
1990 Present Value of Inflated Cost:	$122.8	$90.4	$213.2

8. ATC PROVIDER COST

Plans for incorporating ADS-based operational capabilities are being pursued by various ATC provider authorities. Programs plans are reported (4) for Australia, Canada, Iceland, Japan, Portugal, Spain, the United Kingdom, the Union of Soviet Socialist Republics, and the US. Most of these ATC provider authorities have jurisdiction over CTAs, oceanic control areas (OCAs) and FIRs in the North Atlantic and Pacific. These include:

North Atlantic	Canada	Gander CTA/FIR
	Iceland	Reykjavik CTA/FIR
	Portugal	Santa Maria CTA/FIR
	United Kingdom	Shanwick CTA/FIR
	United States	New York CTA/FIR
Pacific	Japan	Tokyo OCA/FIR
		Naha OCA/FIR
	United States	Anchorage CTA/FIR
		Oakland CTA/FIR

Canada also is considering ADS implementation in its northern domestic airspace. Australia's airspace jurisdiction does not adjoin those of the US or Japan and is south of the Pacific oceanic airspace under study.

The US New York CTA/FIR includes oceanic airspace that was part of the US San Juan CTA/FIR prior to reconfiguration under a US oceanic ATC consolidation program. The US currently is not implementing ODAPS at the Anchorage Center. Hence, this study assumes ADS implementation in the northern Pacific would be preceded by the establishment of an ODAPS baseline ATC capability at the Anchorage Center.

ATC provider costs for incorporating ADS, exclusive of ODAPS baseline establishment requirements, are estimated by the FAA, ARD-100, in 1990 dollars as follows:

Research and Development	$7.0 million per provider authority
Facility and Equipment	$7.0 million per ATC center

These estimates represent the US ADS program. Cost estimates for non-US ADS programs have not been obtained. Lacking other data, the US cost estimates are used, subject to revision, to represent the ADS programs of other provider authorities. The annual maintenance cost for an ATC system is estimated (6) to be 5% of the initial facility and equipment cost. But, since ADS equipment includes replacement of some ODAPS equipment, the additional annual maintenance cost rate due to ADS relative to the baseline rate is estimated to be 2.5%. This estimate is equal to $175,000 per year per center in 1990 dollars.

Table 25 shows the result of extending the US cost estimates to other ADS programs. The annual cost estimates in Table 25 assume that a $7.0 million research and development expenditure is spent uniformly by each of the six provider authorities at a rate of $2.333 million per year during 1990 through 1992, which is $14 million annually for a total of $63 million. A $7.0 million facility and equipment expenditure for each of the nine ATC centers is assumed to be equally distributed among 1992 and 1993, which totals $63 million. This schedule allows for the initiation of pre-operational ADS system shakedown tests in 1993 and their continuance in 1994. Maintenance costs are assumed to be incurred at a rate of $175,000 per year per center during 1993 through 2010, which totals $1.58 million annually for nine ATC centers. Table 25 shows total costs accumulated during 1990 through 2010 with and without a 5% compound annual inflation rate and shows the present value of the inflated costs based on a 10% discount rate. The estimated total present value ATC provider program cost for all years and sites is $113.3 million.

Table 25. ATC Provider Costs

ATC Provider Cost ($ million)

Year	Research and Development	Facility and Equipment	Maintenance	Total
1990	$14.00			$14.00
1991	$14.00			$14.00
1992	$14.00	$31.50		$45.50
1993		$31.50	$1.58	$33.08
1994			$1.58	$1.58
1995			$1.58	$1.58
1996			$1.58	$1.58
1997			$1.58	$1.58
1998			$1.58	$1.58
1999			$1.58	$1.58
2000			$1.58	$1.58
2001			$1.58	$1.58
2002			$1.58	$1.58
2003			$1.58	$1.58
2004			$1.58	$1.58
2005			$1.58	$1.58
2006			$1.58	$1.58
2007			$1.58	$1.58
2008			$1.58	$1.58
2009			$1.58	$1.58
2010			$1.58	$1.58
All	$42.0	$63.0	$28.4	$133.4

	Research and Development	Facility and Equipment	Maintenance	Total
Cost with Inflation:	$44.1	$71.2	$51.3	$166.6
1990 Present Value of Inflated Cost:	$40.1	$56.1	$17.1	$113.3

9. ADS BENEFIT AND COST IMPACT EVALUATION

Savings and costs attributable to ADS are compared in this section, and considerations pertaining to saving and cost sensitivity factors are examined.

9.1 Saving and Cost Comparison

A compilation of the estimated costs and savings, including adjustments for ADS limitations, is presented in Table 26. This table tabulates the 1990 present value estimates totalled for all traffic flows in the years 1990 through 2010 for the North Atlantic and Pacific. Estimates are based on compound annual inflation rates of 5% for fuel price and 5% for other costs, a discount rate of 12% for flight cost savings, air-ground communication system user costs, and ADS aircraft equipment and maintenance costs, and a discount rate of 10% for governmental ATC provider facility and equipment and maintenance costs. The use of different discount rates to calculate present values is based on the previously accepted practice (7) of distinguishing the investment decision evaluation procedures employed by aviation industry and government authorities.

Table 26 shows a potential net savings of $176.6 million due to ADS implementation. This estimate assumes ADS operations starting in 1995 with 100% ADS fleet equipage.

Potential cost savings due to ADS-based safety benefits have not been quantitatively estimated and are not represented in Table 26.

9.2 Sensitivity Analysis

The potential net savings are subject to uncertainties concerning cost estimation factors. These factors include fuel price and ADS aircraft communication equipage cost, which are the major components of the saving and cost comparison.

<u>Fuel Price</u> -- The dominant component of flight cost savings is fuel. The higher the fuel price, the greater the flight cost savings. Hence, an excessively high fuel price estimate would cause an overestimate in potential savings. The affects of lower fuel prices than that estimated is evaluated holding all other costs fixed. A decrease in the estimated 1990 base fuel price from 1.00 to 0.75 $/gallon would reduce net savings, but would retain a net advantage of $53.9 million. A reduction in the compound annual fuel price inflation rate from 5% to 2% while retaining the estimated 1990 base price of 1.00 $/gallon would result in a net saving of $34.1 million.

<u>ADS Aircraft Communication Equipage Cost</u> -- The analysis allocates the aircraft satellite communication equipment costs according to the relative usage assumed for ADS air traffic services versus non-ADS aircraft operator functions. The proportion of the aircraft equipage cost allocated to ADS is 50%. An increase in the ADS cost allocation to 75% would reduce estimated net savings, but would retain a net advantage of $69.9 million assuming all other costs are fixed as previously estimated.

Table 26. Saving and Cost Comparison

Cumulative Savings and Costs 1990-2010 (Discounted 1990 US $ millions)

Category	North Atlantic	Pacific	Subtotal	Total
Flight Cost Savings Due To:				
Reduced Separation Minima	$290.3	$212.4	$502.7	
ATC Flexibility	$17.0	$24.7	$41.7	
Total Savings				$544.4
ADS Air-Ground Communication User Cost Increase			$41.3	
Aircraft Communications Equipment Costs:				
Purchase & Installation			$122.8	
Maintenance			$90.4	
Subtotal			$213.2	
ATC Provider Costs:				
Research & Development			$40.1	
Facility & Equipment			$56.1	
Maintenance			$17.1	
Subtotal			$113.3	
Total Costs				$367.8
NET SAVINGS				$176.6

9.3 Benefit and Cost Study Considerations

The scale of this interim study precludes more detailed assessments of various issue alternatives pertinent to ADS benefit and cost analysis. Such issues should be addressed in further analysis efforts. For example, the consequences of partial ADS fleet equipage and the continuation of an HF communication service are jointly related and complex. A mixed ADS and non-ADS aircraft environment would require provision of HF air-ground voice communication service in parallel with ADS satellite data link communication service. However, the operational requirements of the HF system in a mixed HF/ADS environment would not be as extensive as in an all-HF equipage environment. Alternatives for the HF operation in the mixed environment could range from continuance of the baseline HF system, with or without reduced staffing, to implementation of a residual HF system. The residual HF system may be designed to handle a relatively low message loading, perhaps with fewer HF communication facilities. The practicality of altering the HF system would depend on technical, operational and related factors. Similarly, ATC operational and technical complexities would affect the range of procedural alternatives appropriate for controlling a mixture of ADS and non-ADS air traffic. Also, the extent to which HF service should properly be considered as part of ADS service costs and the allocation of network distribution and support costs between HF and ADS services should be addressed. The cost impacts pertaining to these considerations require careful investigation based on data beyond those currently assembled.

A related aspect concerns the cost of continuing the baseline HF air-ground voice communication system as an alternative to ADS implementation. Recall, for lack of definitive information, the user cost recovery requirement estimated for continuing the baseline HF system without ADS assumes no major HF system expansion during 1990 through 2010. But, such expansion may be required to accommodate future traffic growth. The cost of a baseline HF system expansion would further increase the net saving associated with ADS, which would tend to offset potential reductions in net savings attributable to partial ADS aircraft fleet equipage with joint HF/ADS service.

The usefulness of information enhancement applies to the various benefit and cost analysis factors. Further clarification and specification would be of value for data pertaining to non-US costs, ATC system operations and costs, ADS and HF air-ground communication cost recovery requirements, message loading, aircraft equipage schedules and costs, Pacific traffic operations, flight diversion and delay costs, traffic forecasts and newly expanding traffic markets in Europe and Asia, and safety enhancements. In general, continual updates of these and other factors would be worthwhile to further refine an understanding of the potential impacts of ADS implementation decisions. To this end, an invitation is extended to the international aviation community to provide additional quantitative data describing operations and costs as deemed appropriate.

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